EVALUATING THE EFFECTS OF USING ANNUALLY ESTABLISHED UNDER-VINE COVER CROPS IN NORTHEASTERN RIESLING VINEYARDS

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ABSTRACT

Given the rising concerns of herbicide resistance and environmental contamination, investigating ways to eliminate herbicide use in vineyards is warranted. In two Finger Lakes vineyards, cover crops were established annually beneath Riesling vines and compared to a glyphosate-sprayed strip. At one site, natural vegetation, buckwheat, and annual rye grass underneath vines were not found to impact measures of vine growth, yields, or juice characteristics, but did cause differences in wine aroma. At the second site, buckwheat, chicory, and herbicide were maintained beneath vines, with and without irrigation. Using buckwheat did not impact vine growth or yield, but chicory reduced vegetative growth, yields, and titratable acidity in the second year. All treatments were also found to create differences in perceived wine aroma. Further testing of how different under-vine cover crop species affect vine growth and resulting wine aromas in Northeastern Riesling will help provide grape growers with sustainable alternatives to herbicide.

BIOGRAPHICAL SKETCH

Lindsay Jordan was born in Glendale, California on October 17th, 1988 and grew up in Carmel, California. Pursuing a love of grapes and wine, she worked the 2010 harvest with Mumm Napa and participated in undergraduate research in the lab of Dr. Mark Matthews examining xylem flow in *Vitis* species. She graduated summa cum laude from University of California, Davis with a Bachelors of Science in Viticulture and Enology in 2011. She then joined the Cornell University Department of Horticulture for her Masters studies, working with Dr. Justine Vanden Heuvel. During her graduate studies, she was the recipient of several awards and scholarships, including the American Society of Enology and Viticulture Michael Vail award, American Society of Enology and Viticulture Eastern Section Best Student Paper in Viticulture, and a recipient of the Northeastern Sustainable Agriculture Research and Education Graduate Student Grant. She was also the fortunate recipient of the Cornell University Frederick Dreer Award that enabled her to travel to New Zealand in 2014 to work on an under-vine management project through the Eastern Institute of Technology as a visiting graduate student researcher and work the 2014 vintage with Pernod Ricard Winemakers. She will be returning with her beloved dachshund Espresso to California, to work the 2014 harvest.

DEDICATION

I dedicate this thesis to the friends that have become my family on the west and east coasts.

And especially to Stephanie Beeks, Franny Doerflinger and Erin McKeon.

It was with you, that I survived Cornell.

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PREFACE

This dissertation is original, unpublished, independent work by the author, Lindsay Marie Jordan.

Chapter 1. Literature Review

Herbicide Use and Risk in Vineyards

Herbicides are by far the most applied pesticide in the United States, with the total volume of herbicides used equaling the volumes of insecticides, fungicides and other pesticides combined (Grube et al. 2011). In 2007, 442 million pounds of herbicides were applied for agriculture in the United States, costing $4.2 billion dollars (Grube et al. 2011). Herbicide use is prevalent in vineyards to control weed growth between and within vine rows. With any herbicide use, there is a risk of non-target plant effects, development of resistance, and environmental and biological toxicity.

Pre-emergent herbicides are still widely used in vineyards throughout the world to manage ground floor vegetation, but run a high risk of environmental contamination. Six years of annual applications of pre-emergents in a Concord vineyard showed that 3-(*p*-chloro-phenyl)-l, l-dimethylurea (monuron), 3-(3,4-dichloro-phenyl)-l,l-dimethylurea (diuron), and 2-chloro-4,6-bis (ethylamino)-*s*-triazine (simazine) persisted in the top 12 inches of the soil for least a year after the initial application (Dawson et al. 1968). The potential for runoff and leaching of pre-emergent herbicides has been documented in vineyard soils (Landry et al. 2006) and the presence of vineyards and orchards in a watershed was highly correlated with simazine in surface water samples (Phillips et al. 2002). Ultimately, the long lasting nature and potential for contamination of surface and ground water sources by pre-emergent herbicide use in vineyards poses a large risk to the surrounding environment.

Instead of using pre-emergents, many grape growers rely on contact herbicides, predominately (N-(phosphonomethyl)glycine) (glyphosate), to control weeds in the vineyard. The Environmental Protection Agency Pesticides Industry Sales and Usage report documenting pesticide use up to 2007 cited that approximately 185 million pounds of glyphosate was applied for agricultural use and it was the most commonly used active ingredient of all applied herbicides in the United States (Grube et al. 2011). Glyphosate has become such a successful and widely adopted herbicide not only for its effective mode of action, but also because glyphosate has been considered to be a relatively safe alternative to other conventional herbicides, with low reported environmental and health risks (Duke and Powles 2008). Glyphosate is known to sorb to soil and has been found to rapidly, microbially degrade over time (Rueppel et al. 1977; Schnurer et al. 2006). Because of these characteristics, glyphosate has been considered to be at low risk for contaminating water sources; since it was not thought to be readily leachable, glyphosate has been considered the safer alternative to pre-emergents for vineyards.

However, glyphosate use is not without risk. Runoff of glyphosate has the potential to reach damaging levels when application and precipitation events aligned (Edwards et al. 1980). There is evidence that glyphosate can be released by the roots of target plants into the rhizosphere and be taken up by non-target annual plants as soon as two days after application, resulting in decreased micronutrient uptake and plant growth of the adjacent indicator species (Neumann et al. 2006). Research has shown glyphosate can have a toxic effect on the populations of soil microbes within vineyards (Renaud et al. 2004; Schnurer et al. 2006). Herbicides are not only a risk to microbial populations, but also to humans. While conventionally thought to be a safer alternative than most herbicides, glyphosate has been shown to disrupt mammalian cytochrome P450 enzymes and glyphosate exposure has been linked to the development of many diseases associated with a Western diet including gastrointestinal disorders, heart disease, cancer, diabetes, and Alzheimer's (Samsel and Seneff 2013). From direct exposure of applied herbicide or through contamination of water sources, herbicides can be damaging to the environment and toxic to organisms. Given the risks of using herbicide, alternative and more sustainable ground floor management practices are needed for vineyards.

Cover Crops: A Beneficial Alternative

Acknowledging the environmental risks of herbicide use and to embrace the mandates of sustainable and organic grape growing, many vineyards rely on tilling under-vine rows for weed control. However, repeated soil cultivation poses a risk to long-term soil health in vineyards; tilling has been found to increase soil erosion (Martinez-Casanovas and Sanchez-Bosch 2000) and the concentration of dissolved organic carbon and nitrogen in leachate (Karl et al. 2014). Current alternatives to tilling for organic weed management in under-vine rows include mulches and geotextiles, but both options have high associated material and labor costs and were not found to have any consistent benefit to soil organic matter, vine nutrient content, or fruit composition compared to conventional tilling (Hostetler et al. 2007).

To eliminate herbicide use and cultivation in the vineyard, grape growers can choose to manage vegetation on the vineyard floor as a sustainable alternative. Using cover crops as living or mowed mulches has been successfully used for weed control (Fredrikson et al. 2011; Steinmaus et al. 2008) and to reduce populations of troublesome species of weeds including horseweed and sowthistle (Sanguankeo et al. 2009). Interrow cover crops have many well-documented benefits in vineyards including reducing soil erosion (Ruiz-Colmenero et al. 2013), reducing the risk of surface runoff (Celette et al. 2005), reducing compaction (Morlat and Jacquet 2003; Ruiz-Colmenero et al. 2013), improving soil characteristics including organic matter content and pH (Morlat and Jacquet 2003; Sicher et al. 1993). Cover crops have also been found to promote increased organism diversity in the vineyard including enhancing beneficial predators and parasites of grape pests (English-Loeb et al. 2003; Nicholls et al. 2000), soil microbes (Ingels et al. 2005,) and mychorrhizae (Baumgartner et al. 2005). Currently to exploit the aforementioned benefits of cover crop use, many grape growers in the Finger Lakes region maintain vegetation between vine rows, but keep the area directly beneath vines vegetation free, most commonly with herbicide. The vineyard floor management practice of maintaining a bare under-vine row is commonly seen in arid climates in order to reduce the perceived competition for finite resources like water and nutrients. However, very little research has been done examining cover crop use in under-vine rows, which could offer a sustainable and soil health promoting alternative to herbicide or tilling in vineyards in the cool and humid climate of upstate New York. Further investigation of how under-vine cover crops affect grapevines is warranted to promote sustainable vineyard floor management choices.

In climates where water may be limiting to grapevines, the conventional vineyard floor management practice is to reduce any competition for water by eliminating vegetation. Post-veraison water deficits are known to result in lower midday leaf water potential readings and early season water deficits were found to greatly reduce yield components and berry size (Matthews and Anderson 1989). Increasing water stress was found to correlate with reduced leaf area and grape yields at harvest in Shiraz (Ginestar et al. 1998). Water deficits applied to potted Riesling grapevines significantly reduced shoot and lateral growth and leaf and berry size (Reynolds and Naylor 1994). Therefore, understanding whether cover crops would induce water stress is critical to developing a better understanding of how under-vine cover crops would impact vine vigor and fruit characteristics.

Vegetation maintained in interrows of vineyards has been found to reduce water content in vineyard soils in a variety of studies (Lopes et al. 2008; Tesic et al. 2007; Wheeler et al. 2005). Increasing vineyard floor native vegetation coverage was found to correspond with decreased volumetric soil water content and increased soil moisture tension in a hot, semi-arid climate but exhibited a less pronounced, but still evident effect in a mild, semi-humid climate (Tesic et al. 2007). Yet a reduction in soil moisture has not always correlated with increased vine water stress. A cover crop mix of perennial grasses and clovers established in alleyways of Oregon Pinot noir vineyards was found to reduce volumetric soil moisture, but this effect did not carry over to any impact in measured leaf water potential (Sweet and Schreiner 2010). In other studies, various cover crop species were not found to consistently impact predawn leaf water potentials, stomatal conductance, or photosynthetic rates of grapevines (Celette et al. 2005; Ingels et al. 2005; Morlat and Jacquet 2003). Even in more arid climates than the Northeast, past research shows that while soil water content can be affected by cover crops, this does not necessarily translate to significant competition for water to generate an effect on vine water potential.

By understanding that cover crops rarely impact vine water potential in warmer and drier climates than the Northeast, there is even less justification to maintain bare soil beneath vines in cool and humid climates. Predawn leaf water potentials of -0.16 to -0.18 MPa were measured for conventionally grown Riesling in upstate New York throughout the entire 2007 season, indicating soil water availability was not a limiting factor in the region for the season (Intrigliolo et al. 2009). The same vines never exceeded the midday stem water potential of -1.0 MPa, a threshold for the onset of reduced leaf photosynthesis in Riesling (Intrigliolo et al. 2009). In one study in the humid American Mid-Atlantic region, red fescue (*Festuca rubra* L.) planted directly underneath vines was found to consistently reduce soil moisture at a depth of 0.6 m, but not at 1 m (Hatch et al. 2011). In the same study, midday stem water potentials of vines in the under-vine cover crop treatment were found to be reduced compared to herbicide treatments, but by never more than 0.2 MPa (Hatch et al. 2011). Maintaining mowed resident vegetation beneath vines was found to slightly reduce midday stem water potentials in vineyards in the Marlborough and Hawke's Bay regions of New Zealand, but not consistently (Krasnow et al. 2013). Previous work indicates that extending vegetation coverage to under-vine rows would minimally impact on midday water potential and does not create water stressed conditions in humid climates.

Even without a reduction in water potential of the vines, cover crops may still alter vine growth. Studies have found that while leaf water potentials were not strongly influenced by interrow plantings of sod cover crops compared to bare soil treatments, there was still a reduction in measures of vegetative growth and yields in Cabernet Sauvignon in the Loire Valley (Morlat and Jacquet 2003), Sauvignon blanc in the south of France (Celette et al. 2005), Merlot in California (Ingels et al. 2005), and Gewürztraminer in Canada (Reynolds et al. 2005). Morlat and Jacquet (2003) attributed the reduction in growth as a vine adaptation response to a reduced water supply (2003). So even without a measurable difference in vine water potential, cover crops may still induce grapevines to alter growth due to competition for water, even if sufficient water stress is not created to alter vine water potential. How cover crops can alter vine growth characteristics by reducing water availability warrants further investigation to understand the potential effects of using cover crops as a sustainable alternative to herbicide.

However, cover crops may alter grapevine growth through mechanisms other than competition for water. Cover crops have been consistently found to reduce the concentrations of important macro and micronutrients in grapevines. In Mediterranean climates, a permanent cover of tall fescue (*Festuca arundinacea* Shreb.) was found to reduce nitrogen in the soil solution and shoot tissue (Celette et al. 2009) and plant nutrient concentrations in grape tissues of N, Mg, and Ca were depressed when grown with interrow cover crops of tall fescue and natural vegetation (Sicher et al. 1993; Tesic et al. 2007). Mowed and unmowed perennial rye grass (*Lolium perenne* L.) planted in an irrigated Chardonnay vineyard in the cool climate of Oregon was found to reduce total nutrient content of grape leaves collected in the Fall compared to herbicide treated rows, with significant reductions in N, P, K, S, Mg, Mn, Fe, Cu, B, and Zn (Tan and Crabtree 1990). In both warm semi-arid and cooler, semi-humid regions in Australia, N and Mg concentrations in petioles at bloom were lower for natural vegetation sward treatments than bare soil (Tesic et al. 2007). Across both warm and cool climate wine regions, a reduction in nutrient content – specifically nitrogen – in grapevine tissue is a common trend seen among cover crop studies.

This depression of nutrient content is attributed as a possible cause of the reduction in vine growth seen in cover crop studies, even when soil and/or leaf water potentials were not affected. Nutrient uptake of the vine may to be restricted by cover crops, since cover crops have been found to reduce the number of roots in upper soil layers and cause a deeper, less branching root growth pattern that does not access this nitrogen in the topsoil (Morlat and Jacquet 2003). In one study, an interrow cover crop of tall fescue did not significantly impact predawn leaf water potentials or stomatal conductance of grapevines compared to herbicide sprayed interrows. There was a reduction in vegetative and reproductive growth compared to the herbicide treatment. This effect was attributed to other competition mechanisms induced from the cover crop, like allelopathy or reduced nitrogen mineralization (Celette et al. 2005). A cover crop study in California found consistent differences in leaf water potential among treatments, but the native grass mix had the lowest petiole and leaf blade nitrogen content of all the tested species mixes and also resulted in the lowest pruning weights and fresh shoot weights (Ingels et al. 2005). In two under-vine vegetation studies in humid climates, significant reductions in vegetative growth were found and minimal differences in stem water potential measured, but nitrogen content was reduced in petioles. Red fescue in the humid Mid-Atlantic region reduced the petiole nitrogen concentration at bloom in the third year of establishment (Hatch et al. 2011). Increased vegetation coverage does not just introduce competition for water, but all plant required resources. Thus, reduction in available nutrients could explain the reduced growth seen even when measures of water potentials were not impacted by cover crops in vineyards.

While seemingly a drawback to cover crop use, reducing nutrients, including nitrogen, may help curtail vigor problems in vineyards where excessive vegetative growth can result from nutrient rich conditions. Increased levels of nitrogen taken up by the vine increased pruning weights, berry mass, and the leaf area on laterals in Sauvignon blanc (Chone et al. 2006) and vines that had increased nitrogen content from fertilization were found to have shoot weights greater than 20 to 30 g/shoot and much larger pruning weights (Spayd et al. 1993). Increasing rates of nitrogen fertilization had a positive correlation with delayed sugar accumulation in Riesling (Spayd et al. 1994). Restricting access to nitrogen through lower fertigation rates at bloom and veraison time petiole nitrogen concentrations at bloom and veraison in Riesling (Spayd et al. 1993). In areas where nitrogen levels are not controlled through fertigation and there is no way to limit access to nitrogen, cover crops could lower nitrogen levels to potentially sufficiently control vigor in rain-fed systems. Low nitrogen levels in grapevines were found to reduce vegetative and reproductive growth more significantly than mild water deficits (Chone et al. 2001). Increasing the proportion of grass coverage in the vineyard with the duration sod maintained was found to correspond an increasing reduction in nitrogen levels in the soil, grapevine leaves, and must (Rodriguez-Lovelle et al. 1997). With the abundant research showing that many different cover crop species are known to reduce nitrogen concentrations of grapevine tissue across many climates, increasing cover crop coverage to under-vine rows could reduce concentrations of nitrogen and subsequently reduce vegetative growth.

Sometimes cover crops were found to enhance nutrient concentrations. A permanent grass cover increased levels of N and K in vineyard soil (Morlat and Jacquet 2003). A grass cover crop was found to enhance K and P contents in Merlot petioles (Sicher et al. 1993). In both studies, decomposition of the cover crop and enhanced biological activity promoting nutrient uptake were the possible explanations for the increased nutrient levels. Future research tailored to specific cool climate and humid vineyard conditions is needed to help clarify how cover crops may promote or discourage nutrient turnover and how they should be managed in a specific region.

It is important to understand that nutrient dynamics are variable, and cover crops will have varying effects within an individual season. There was a timing effect on nutrient competition found for sod and natural vegetation cover crops, where nitrogen values were markedly more reduced in petioles collected from grapevines at fruit set compared to veraison when the competitng vegetation would have been growing most vigorously and there was likely less mineralization of soil organic matter (Pool et al. 1990; Sicher et al. 1993). There is also an interaction effect between soil moisture conditions and nutrient availability that should be considered, where reduced water levels can limit nitrogen mineralization and/or uptake for grapevines (Freeman and Kliewer 1983). How actively growing cover crops in Northeastern vineyard sites affect soil water content and subsequent nitrogen mineralization needs to better understood for better vineyard floor management in cool and humid climates.

Cover Crop Reported and Potential Effects on Vine Growth and Yields

In past research, decreases in soil moisture and nutrient content of soil and grape petioles have been used to explain viticultural and enological effects witnessed in studies examining how cover crops alter vegetative growth measures, juice characteristics, and resulting wine attributes. The impacts of interrow cover crops have been examined in many regions and the reported effects greatly vary across studies. Sometimes little impact on vine growth or yields were found. In rain fed vineyards, cover crop treatments did not affect grape yields (Monteiro and Lopes 2007) or shoot growth, pruning weights, yields, or cluster weights (Sweet and Schreiner 2010). In other studies, sometimes some effects to vegetative growth and yield were measured, but not consistently throughout the course of the study or only after several years of establishment (Monteiro and Lopes 2007). While there were no significant impacts to vines in the first year of establishment in the second to fifth years of study, chicory (Chicorium intybus var. sativum 'Puna') reduced summer hedging and winter pruning weights up to 60% and reduced shoot length up to 50% by the end of the season, but reduced berry weights and berries per cluster only in the fifth year (Wheeler et al. 2005). Seasonal variation and the timing of establishment may largely determine if cover crops significantly affect vine growth in non-arid climates.

In the majority of studies, vegetation restricted to the interrows of vineyards exhibited a devigorating effect on vines across warm and cool climates. A permanent grass sward of *Festuca Arundinacea* cv. Manade in interrows consistently reduced vine pruning weights and leaf area (Morlat and Jacquet 2003). Using a sod cover crop composed of crested wheatgrass (*Agropyron cristatum* L.) and sheep fescue

(*Festuca ovina* L.) resulted in a reduction in pruning weights, lateral shoots, clusters per vine, yield per vine, cluster weight, berries per cluster, and berry weights intermittently across six years of study in a Gewurztraminer vineyard in British Columbia (Reynolds et al. 2005). Over many different wine-growing regions, studies have shown that a variety of interrow cover crops can devigorate a vineyard by reducing vegetative growth.

In regions were vegetative growth can be excessive, there is the potential to exploit the documented devigorating effects of cover crops, specifically in the Northeast where vegetation is already maintained in the interrows of vineyards, by expanding cover crop use to the under-vine row. An under-vine cover crop of red fescue was found to reduce trunk circumference, shoot growth rate, pruning weights, and crop load value in the humid Mid-Atlantic region (Hatch et al. 2011). In both hot, semi-arid and milder, more humid regions of Australia, complete vineyard floor coverage with resident vegetation compared to just interrow cover or bare soil maintained with herbicide reduced pruning weights, shoot lengths, and yields (Tesic et al. 2007). Studies showed that under-vine cover crops improved canopy characteristics, reducing the number of internal clusters (Tesic et al. 2007), reducing leaf area and increasing percent gaps in the canopy (Krasnow et al. 2013), and increasing the cluster and leaf exposure flux availability (Hatch et al. 2011). Studies examining under-vine cover crops in humid climates as an herbicide replacement indicate that under-vine groundcovers cause a reduction in vegetative growth and an alteration of canopy characteristics.

The reduction in vine growth sometimes seen with cover crop use may not be detrimental to the goals of a premium grape grower. Decreasing shoot and lateral growth and leaf area will improve light penetration and reduce shade in the canopy, which is well linked with increased bud fruitfulness and yields, reduced incidence of disease, enhanced fruit composition (Smart 1986) and reduced bud necrosis (Vasudevan et al. 1998). Currently, to mitigate excessive vigor, many growers must rely on expensive manual labor like leaf and shoot thinning or time-costly mechanical operations like repeated hedging if they wish to manipulate the canopy light environment.

Excessive vegetative growth not only leads to shading, but also upsets the equilibrium between vegetative and reproductive growth of a vine. For divided canopy systems in several wine grape varieties, crop yield/pruning weight ratios between 5 and 10 were considered well balanced, capable of ripening their crop load for high quality wine production (Kliewer and Dokoozlian 2005), with a crop load ratio between 9 and 10 specifically recommended for Riesling (Spayd et al. 1993). If values exceed the optimal ratio for vine balance, a vineyard would benefit from a reduction in vegetative growth. Studies examining Riesling have shown that double fruiting zone training systems which try to alleviate the problem of excessive vigor can still produce excessively dense canopies (Reynolds et al. 1996). In an area where a vigor problem has been identified and the training system already adjusted, cover crops can offer growers a tool to help control unwanted vigor in the field.

In previous studies, interrow cover crops have helped alleviate excessive vigor and yield concerns in vineyards. In a Portuguese study in a Cabernet Sauvignon vineyard that experienced over 700 mm of annual precipitation, natural vegetation and other living mulches have been suggested as an alternative vineyard floor management option, but further studies to evaluate specific cover crop species selection are needed

(Monteiro et al. 2008). In the Trentino region of Italy, excessive vine growth and yields exceed the mandated DOC standards frequently in vineyards. Cover crops were found to reduce pruning weights and yields compared to cultivated and herbicide treatments to levels in greater accordance with DOC regulations and to reduce levels of botrytis at harvest (Sicher et al. 1993) The reported reduction in vegetative growth measures induced by cover crop use was found to bring vines closer to the desirable Ravaz index values for vine balance in a study on Cabernet Sauvignon in Portugal (Monteiro and Lopes 2007). Using cover crops has shown potential to alter vegetative growth and promote more optimal vine balance for wine production.

In one study, tilled soil was compared to grass, clover, and cereal cover crops planted between rows and the cover crops were found to have very little impact on pruning weights of vines and had no significant effect on fruit yields or juice characteristics. The lack of any effect of cover crops was attributed to the large 0.7m herbicide strip maintained between the cover crops and vines (Ingels et al. 2005). Even in a warm climate, Zinfandel grapevines were found to tolerate up to 105 g/m^2 of vegetation in under-vine rows, with no to minimal reductions in yield measures compared to weed-free herbicide controls; this study shows that vines were able to tolerate a certain level of competition and under-vine weed control for the first part of the growing season could be unnecessary depending on soil moisture conditions (Sanguankeo et al. 2009). In cooler, more humid climates, vegetation cover could be promoted by seeding cover crops in under-vine rows in lieu of spraying herbicide to control weeds or seeding to promote plant densities greater than $100 g/m^2$ that would induce competition. To promote the greatest potential for inducing competition with grapevines, under-vine cover crops could be used to increase the area of competing vegetation and result in altered vine and juice characteristics in areas that are already using interrow cover crops.

Cover Crop Effects on Juice and Wine Quality

The reported effects on juice chemistry and wine attributes when using cover crops vary greatly. Cover crops, with their potential to alter vine growth, canopy characteristics, and nutrient and water status of the soil and vine, have great potential to alter juice characteristics and impact sensory attributes of wine.

Sometimes, juice quality has been improved through cover crop use in non-irrigated vineyards. Resident vegetation and a sewn cover crop of legumes and grasses reduced titratable acidity in must by 0.8 to 1.36 g/L compared to a bare soil maintained with cultivation (Monteiro and Lopes 2007). Chicory planted in vineyard rows was found to increase soluble solids by at least 2.2°Brix and decrease titratable acidity by 2.45-3.11 g/L compared to bare soil maintained with glyphosate or cultivation (Wheeler et al. 2005). Decreased acid levels and accelerated sugar accumulation could greatly benefit cool climate vineyards where allowable hang time to optimize sugar to acid ratios is limited by the climate.

Sometimes, there was no reported effect of cover crops on juice characteristics (Ferrara et al. 2012; Monteiro and Lopes 2007; Pool et al. 1990; Sweet and Schreiner 2010; Tesic et al. 2007). Counter to the majority of previous work, a sod alleyway was found to delay ripening resulting in lower Brix and pH and higher TA values in Gewürztraminer in British Columbia compared to cultivated and herbicide treatments in one study (Reynolds et al. 2005). More work is needed to understand how cover crops in under-vine rows could affect juice characteristics in cool climates like the Northeast.

Ultimately the end product of vineyard production is the finished wine and the effects of choices made in the vineyard on the resulting wine must be considered. Some studies have examined the direct effects of cover crops on wine quality, although none have studied the impact under-vine cover crops on wine attributes in a high precipitation growing area. Using cover crops instead of maintaining bare soil has been found to increase anthocyanins and tannins in red wine varietals (Monteiro and Lopes 2007; Cortell et al. 2005). In many studies, cover crops resulted in different aromatic precursors and compounds that would have a large impact on wine quality. Using sod in alleyways resulted in the greatest potential volatile terpenes measured by steam distillation in Gewürztraminer at veraison, but with lower free volatile terpenes than cultivation and herbicide treatments (Reynolds et al. 2005). This indicates cover crops may potentially enhance precursor development, but how this translates into the free volatiles that would impact wine aroma needs clarification. In Cabernet Sauvignon, the use of several different cover crop species in interrows was found to significantly increase important wine aromatic compounds and wine scores compared to a cultivated control. Concentrations of ethyl acetate (fruity/sweet), isoamyl acetate (fresh, banana), eight different ethyl esters (fruity aromas), higher alcohols, terepnes and norisoprenoids including citronellol (clove/anise), beta-damascenone and alpha-ionone (canned peach, baked apple), and fatty acids were all found to be increased and were present above sensory thresholds for each compound (Xi et al. 2011). Wine grapes grown with cover crops have been found to yield better wine attribute scores in Cabernet Sauvignon than bare soil treatments (Xi et al. 2011). By using cover crops in the vineyard, there is the potential to directly influence the aromatic development and later volatiles in the wine, indicating cover crops have a strong potential to directly influence wine quality.

Restricting water availability has been found to increase wine grape quality. Even very minimal differences to vine water potential can have strong impacts in wine flavor and aromas. Early and late season water deficits that caused leaf water potential to be just 0.3 MPa lower than a well irrigated control produced Cabernet franc with increased juice phenolics and skin extracted anthocyanins (Matthews and Anderson 1988). If even a small difference of 0.3 MPa can have significant beneficial effects on fruit aromas in wine, then there could be great benefits by even slightly lowering the water potential of vines through the use of under-vine cover crops in humid regions. However, there is a balance that must be struck between introducing water stress that benefits wine quality and maintaining sufficient enough water for proper plant function. For Sauvignon blanc, mild water deficit was found to benefit wine aroma potential, increasing concentration of aroma precursors of volatile thiols associated with box tree, citrus zest, grapefruit and passion fruit aromas. Severe water stress, however, reduced the concentration of these precursors (des Gachons et al. 2005). In the cool and humid Northeast where severe water stress is rare, cover crop species could be managed to have little to no deleterious impact on vine water potentials, while possibly inducing a minimal level of stress that would be beneficial.

In one case, using deficit irrigation was not found to significantly reduce the midday leaf water potentials compared to the water status of fully irrigated vines. But by reducing the water available to the vine through deficit irrigation, vegetative growth was inhibited, resulting in an increase of total berry skin anthocyanins and total phenols in Moscatel and Castelão due to increased light penetration in the fruiting zone (Chaves et al. 2007). Even if cover crops do not sufficiently compete with grapevines in humid climates with abundant water availability to reduce measurable stem water potentials, there is still the potential for them to alter viticultural characteristics enough to subsequently improve fruit and wine quality.

Knowing that cover crops have been reported to reduce levels of certain nutrients in soil, vines, and must, it is critical to consider the potential nutrient limiting effects on the resulting wine. Reduced nitrogen content of vines is linked with lower nitrogenous compound concentrations in fruit, including yeast assimilable nitrogen (YAN); low YAN values lead to sluggish or stuck fermentations and the production of undesirable aromatic compounds like hydrogen sulfide (Bell and Henschke 2005). However, high YAN values are associated with protein hazes, risk of microbial instability, and increased volatile acidity and acetic acid concentrations (Bell and Henschke 2005). As long as YANs were not reduced to be limiting, a decrease in nitrogen caused by introducing competing vegetation could benefit fruit and wine quality. Low nitrogen values in must were found to induce higher concentrations of berry tannins and anthocyanins and reduced berry size in Cabernet Sauvignon more effectively than water stress (Chone et al. 2001). However, in Sauvignon blanc, nitrogen deficiency was found to decrease wine aroma. The extra nitrogen uptake decreased critical aroma precursors in the grapes and created conditions that released volatile thiols, resulting in a lower phenolic content of the wine (Chone et al. 2006). More research to better understand how nutrient concentrations alter wine aroma and flavor development could help clarify the complicated relationship of how cover crop nutrient competition affects wine quality.

Studies have shown that there is an important interplay between water availability and nutrient content that will affect the impacts of cover crops on grapevines. In a terroir study in Bordeaux, France, vines with a low vine nitrogen status with no water deficits and vines with a medium nitrogen content with mild water deficits yielded the most preferred wines when tasted by a professional panel (Chone et al. 2001). The highest aroma potential for Sauvingon blanc was found in mildly water stressed and non-limiting nitrogen treatments and depressed nitrogen levels were associated with lower volatile thiol precursor concentrations (des Gachons et al. 2005). Cover crops are one tool grape growers may be able to use to manipulate field conditions or the right combinations of water and nitrogen availability that result in the preferred wines.

Using cover crops in vineyards as an alternative to bare soil maintained with herbicide or cultivation has many widely reported benefits. However, growers must consider the potential competition effects from introducing vegetation to the vineyard floor. In climates where optimal vine balance is typically achieved, changing vine growth and yield could be deleterious. But cover crop use in areas where vines are excessively vigorous, like in the cool and humid Northeast, could result in improved vine balance and wine quality as a result of reduced vine vegetative growth. It is already commonplace to use interrow cover crops in the Northeast, but the area beneath vines is still traditionally kept bare, a management choice that still leaves the vineyard at risk for erosion and the environmental damage of cultivation and herbicide use. Some work has been done examining the use of under-vine cover crops in vineyards, but only in warmer climates where permanent vegetation can be maintained year round beneath the vines (Hatch et al. 2011). In the Northeast where growers must hill soil at the base of vines to protect the graft union in winter and then de-hill in the spring, using permanent cover crops like those that have previously studied is not an option. Annually established under-vine cover crops may potentially offer the cool, humid climate the Northeast an environmentally sustainable alternative to herbicide and cultivation that promotes soil conservation and health. Research to understand exactly how using under-vine cover crops affects the water and nutrient content of the soil and vines, vegetative growth and yields, and resulting juice and wine characteristics is critical for an emerging wine producing region like the cool and humid American Northeast to adopt sustainable practices in vineyard floor management.

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Chapter 2. Evaluating the Use of Annual Species of Vegetation in Under-vine rows in a Commercial Finger Lakes Riesling Vineyard

Introduction

Bare soil is traditionally maintained beneath vines with cultivation or herbicide. However, any herbicide use in the vineyard risks environmental contamination and non-target effects (Dawson et al. 1968; Landry et al. 2006). While many grape growers have adopted the use of contact herbicides, which have less pollution potential than pre-emergents, there are still risks. Exposure to the contact herbicide glyphosate has been found to negatively impact microbial and fungal populations (Renaud et al. 2004; Schnurer et al. 2006) and has been linked with disease development in humans (Samsel and Seneff 2013). Currently, to eliminate herbicide use in the vineyard or for organic grape production, growers must rely on using repeated cultivation under-vines, but cultivation encourages erosion (Martinez-Casanovas and Sanchez-Bosch 2000). Using cover crops in under-vine rows could offer an environmentally sustainable alternative to herbicide and cultivation in vineyards.

Traditionally, the soil directly beneath vines is kept vegetation free with herbicide or cultivation from a fear that vines will be negatively impacted from the induced competition for water and/or nutrient resources. But this conventional thinking may not apply to all grape-growing regions. In the cool and humid Northeast, frequent rainfall throughout the growing season contributes to wet conditions that promote detrimental, vigorous vine growth. Excessive vine growth leads to increased leaf layers which contribute to deleterious canopy shading, reducing fruit quality and resulting in lower sugars and anthocyanins and higher titratable acidity and incidence of disease (Smart 1986). When there is excessive growth, excess shoot and lateral growth and pruning weights can offset the balance between vegetative and reproductive growth and shift values away from the ideal ratios for high quality wine production (Kliewer and Dokoozlian 2005). To manage undesirable vigor to improve fruit and wine quality, growers resort to costly canopy management practices including hedging, leaf pulling, and shoot, lateral, and cluster thinning which merely treat the symptoms of excessive vigor, without treating the cause of the problem.

The competition introduced by cover crops could be beneficial in humid climates that promote excessive vegetative growth. Cover crops in interrows of rain-fed vineyards have been found to reduce measures of vine vigor including shoot and lateral growth, leaf layers in the canopy, leaf areas, and pruning weights (Morlat and Jacquet 2003; Reynolds et al. 2005; Tesic et al. 2007; Wheeler et al. 2005). Cover crops were found to bring vineyard crop loads and vegetative growth measures closer to ideal standards (Monteiro and Lopes 2007; Sicher et al. 1993). An under-vine cover crop reduced measures of vine growth including trunk circumference, shoot growth rate, pruning weights, and crop load value and improved the cluster and leaf exposure flux availabilities in the humid Southeast of the United States (Hatch et al. 2011). Introducing under-vine cover crops in Northeastern winegrowing regions could eliminate herbicide use in vineyards and potentially alleviate excessive vigor, reducing the need for expensive canopy management practices, rather than negatively affect grapevines.

However, unlike in previously studied climates, the Northeast experiences much colder winters that pose a risk to bud survival. To reduce the risk of complete vine death, growers hill-up soil from the under-vine row around the graft union for insulation in the fall, ensuring the survival of scion budwood, and hill-down in the spring at the start of the growing season. These two intensive annual cultivation operations in the under-vine row prohibit the establishment of the previously studied permanent vegetation covers. For the Northeast to adopt cover crops as a sustainable herbicide replacement, how cover crops are established between hilling operations affects grapevines and the resulting wine needs to be examined.

The objective of this research is to compare the effect of three different annual cover crops, buckwheat, annual rye grass, and natural vegetation, planted directly beneath vines compared to a glyphosate sprayed control on vine vegetative growth, yields, vine tissue nutrient content, stem water potentials juice characteristics, and wine aroma.

Materials and Methods

Experimental Setup

This experiment was established in a commercial vineyard in Lodi, NY on the lower east side of Seneca Lake (42.57°N, -76.86°W, 260 m elevation). The soil was predominately Honeye silt loam soil (Soil Survey Staff 1987) on Riesling cl. 198 vines on S04 rootstock planted in 1995 on 2.7 by 1.8 m spacing. Vines were trained in a Scott-Henry system and vertically shoot positioned on 0.90 m and 0.98 m trellis with catch wires for the lower and upper fruiting zones respectively.

Four groundcover treatments were established in a randomized complete block design across four rows of the block and each treatment was replicated four times. In

2011 and 2012 an experimental unit was three panels (12 vines), with the middle panel (4 vines) being used for data collection. Due to a grower herbicide application error in 2013, treatments were established on the data collection panel only, so data collected from the internal two vines with the outer vines of the panel serving as buffer vines.

Treatments were established on an annual basis and were applied to the former herbicide strip, which was approximately 1 m in width. Soil in the former herbicide strip was cultivated by hand using a garden hoe in the top 10 cm. Annual rye grass (*Lolium multiflorum L. perenne var. Italicum*) was hand-seeded at 78 kg/ha in the second week of May and buckwheat (*Fagopyrum esculentum*) was hand-seeded at 390 kg/ha in the last week of May (Earnst Seed Company, Meadville PA). Soil was gently raked over seeds in all treatments. Glyphosate (Roundup® PRO concentrate, Monsanto, St. Louis MO) was applied at 4.7 L/ha when weed emergence was noted in the control plots, which was in the first week of June in 2012 and 2013 and the first week of July in 2013.

Vines were then shoot-thinned to 20 shoots per linear canopy row meter in the first week of June, preferentially removing all secondary and non-fruitful shoots. Vegetative growth was managed throughout the season with vertical shoot positioning and hedging by the grower. Vines were otherwise managed according to standard practices for *Vitis vinifera* plantings in the Finger Lakes region (Wolf 2008).

Climate data was sourced from the Network for Environment and Weather Applications from a weather station within 3km of the research site (42.54°N, -76.87°W, 219 m elevation).

Cover Crop and Weed Biomass and Coverage

At veraison, rectangular framed areas of 0.09 m^2 were used to estimate percent coverage of the cover crop. For each experimental unit, the frame was used to sample two areas within 1 m under-vine row. Frames were gridded with string into a total of 160 squares that were 5.6 cm^2 each. Within the frame, each square was visually evaluated for the presence of cover crop or weeds to measure the percent coverage. Above-ground biomass was collected separately for cover crop and weed species, dried at 65°C for 48 hours, and weighed (Santorius ELT103, accuracy ±0.001, Goettingen, Germany).

Soil Testing

Soil was collected in accordance with the Cornell Soil Health Test (Gugino et al. 2009) sampling protocol after harvest in 2013. Within each treatment replicate, three random samples of approximately 250 mL were taken from the top 20 cm of the soil from the under-vine row, pooled and thoroughly mixed, and dried at 50°C overnight before being submitted for analysis at the Cornell Nutrient Analysis Laboratory (Ithaca, NY) for soil pH and buffer pH, organic matter content from loss on ignition, Morgan extractable nutrient and nitrate concentrations, and wet aggregate stability according to the Cornell Soil Health test (Gugino et al. 2009).

Vegetative Growth Measures

Pruning Weights

Pruning weights of dormant canes from the previous season from harvested vines was taken in late March each year. Each vine within an experimental unit was dormant-pruned to four 10-bud fruiting canes with renewal spurs and the prunings were weighed on a per-vine basis with a hanging scale accurate to 0.01 kg (Salter Brecknell, model SA3N340, Fairmont, MN).

Shoot Lengths

Early in the season, four randomly selected fruitful shoots per data collection vine from each experimental unit were flagged in early June. From that time onward, the shoot lengths were measured from the base of the shoot to the shoot tip using a measuring tape throughout the growing season until the shoot was hedged in late July.

Shoot diameters

At veraison, the internodes of four randomly selected shoots per vine in each experimental unit were measured above their first fully developed nodes using electronic calipers (Kolbat 0.5ft Metric and SAE Caliper, Mooresville NC) to measure the widest and smallest diameters of the oval internode. These two measurements were then averaged for the reported shoot diameter value. For all shoots, to account for oval shapes, two measurements across the larger and smaller radii of the shoot width were taken and averaged for the reported cane diameters.

Enhanced Point Quadrat Analysis

At veraison, the canopy architecture was quantified using the point quadrat analysis (PQA) method described by Smart and Robinson (Smart and Robinson 1991) and the enhanced point quadrat analysis (EPQA) functions published by Meyers and Vanden Heuvel (Meyers and Heuvel 2008). For each vine within each experimental unit, canopy probe insertion measurements were taken every 20 cm along the upper and lower horizontal fruiting zones of the canopy. Photosynthetic photon flux measurements to quantify canopy light interception were taken within 2 days of PQA measurements using a ceptometer (Decagon, model AccuPAR LP-80, Pullman, WA) ±1.5 hours of solar noon on a clear day. For each data panel, the intracanopy photon flux was measured by holding the ambient flux sensor in the unshaded row-middle, while placing the ceptometer parallel to the row within the center of the canopy in the fruiting zone at the height of each fruiting wire. Ten measurements were taken and averaged for calculating canopy light interception characteristics for each vine using EPQA (Meyers and Heuvel 2008).

Vine Water Potential

Predawn leaf water potential ($\Psi_{predawn}$) measurements were taken once a month during the growing season. Measurements were taken between 0330 and 0500 hours using a Scholander pressure chamber (Plant Water Status Console 3000, Soil Moisture Equipment Corp., Santa Barbra, CA, USA). Leaves were enclosed in a 250 cm^2 plastic bag and then cut at the petiole with a razor blade and inserted into the pressure chamber in ten seconds or less. The chamber was then pressurized with nitrogen gas at approximately a rate of 0.1 MPa/sec until xylem sap was witnessed to be exuded from the cut petiole cross section. This pressure was multiplied by -1 to get the $\Psi_{predawn}$ of the vine.

Midday stem water potential (Ψ_{midday}) measurements were taken throughout the growing season within ±1.5 hours of solar noon using the pressure chamber described above. Healthy, well-exposed leaves were enclosed within aluminum foil covered plastic 250 cm^2 bags for one hour before Ψ_{midday} measurements were made. Petioles of bagged leaves were then cut with a razor blade and inserted into the pressure chamber in ten seconds or less and the chamber was pressurized with compressed nitrogen gas at approximately a rate of 0.1 MPa/sec until xylem sap was witnessed to be exuded from the cut petiole cross section. This pressure was multiplied by -1 to get the Ψ_{midday} of the vine.

Petiole Nutrient analysis

From within each experimental unit, 100 petioles in 2011 and 2012 and 60 in 2013 were cut from leaf blades and shoots at veraison. Samples were then gently washed in a mild soap solution, rinsed with deionized water, stored in paper bags and dried at 90°C for one hour. Samples were then submitted to the Cornell Nutrient Analysis Laboratory for combustion analysis of C and N and dry ash extraction of Al, B, Ca, Cu, Fe, K, Mg, Mo, Mn, Na, P, and Zn.

Harvest and Juice Characteristics

At harvest, the grapes from each replicate treatment were hand harvested one day before or on the day of commercial harvest (5 October 2011, 22 September 2012, and 3 October 2013). The total number of clusters per vine was counted and the cumulative cluster weight per vine was measured at harvest using a hanging scale (Salter Brecknell, model SA3N340, Fairmont, MN) and subsequent average cluster weight calculated from these values. For each experimental unit, two 100 berry samples were randomly collected and weighed to determine average berry weight and calculate the average number of berries per cluster.

After weighing clusters at harvest, for each experimental unit, 20 clusters were randomly collected, whole-cluster pressed, and the juice was strained through cheesecloth and frozen at -25°C until processing. Juice was then thawed and warmed in a water bath at 60°C for 30 minutes and allowed to equilibrate to room temperature before analysis of soluble solids, TA, and pH. The soluble solids content was measured using a digital refractometer with temperature compensation (Wilkens-Anderson Company, model ATAGO PAL-1, Chicago, IL for 2011 and 2012, Leica Inc., Buffalo, NY for 2013) and pH was analyzed using a calibrated pH meter (Fisher Scientific, Accumet Basic AB15, Hampton, NH for 2011 and 2012, VWR SympHony, model SB8OP1, Radnor PA for 2013). Titratable acidity (TA) was measured by titrating 10 mL of juice with 0.10 M NaOH to a pH endpoint of 8.2, measured by a pH meter for 2011 and 2012. In 2013 ,TA was measured by titrating a 50 mL aliquot of juice against 0.10 M NaOH top H 8.2 using an automatic titrator (Mettler Toledo, model DL22, Columbus, OH). Juice samples from each experimental unit at harvest were also tested for yeast assimilable nitrogen (YAN) using a Chemwell 2910 Multianalyzer to test for AMM and spectrophotometry for PAN as described by Nisbet et al. (Nisbet et al. 2013).

Winemaking

After harvest, fruit with more than 30% rot was removed. All remaining fruit from the different replicates for each treatment were combined and frozen for 7 days at -12°C and completely defrosted in 2011, and refrigerated at 4°C for 24 hours in 2012 before pressing at the Cornell Orchards Teaching Winery. Fruit was whole cluster pressed using a hydraulic bladder press (Gino Pinto, model Zambelli Hydro 40 Inox, Hammonton, NJ) up to 2 bars of pressure. Juice was treated with 50 mg/L of sulfur dioxide as potassium metabisulfite and Lallzyme C at 2 g/hL (Lallemand Inc., Toulouse, France) before settling for 24 hours at 4°C. Juice from each of the four treatments was then was racked into two five-gallon glass carboys to produce two wine replicates per treatment. Juice was inoculated with 0.25 g/L of *Saccharomyces cerevisae* strain EC-1118 (Lallemand) rehydrated with Go-Ferm as per manufacturer's directions (Lallemand). Carboys were then moved into a 15°C fermentation room and stirred daily. FermAid K (Lallemand) was added at the lag phase (approximately 3 days after inoculation) and after 1/3 sugar depletion at 0.15 g/L and diammonium phosphate supplemented after lag-phase to bring the total YAN of juice to 200 ppm total, inclusive of the FermAid K additions. Wines were fermented until dryness and confirmed to contain less than 0.5% residual sugar with Clinitest tablet (Bayer, West Haven, CT). Wines were then racked into clean carboys and stored at 4°C, with 50 mg/L of sulfur dioxide as potassium metabisulfite added. Wines were not subjected to acid adjustments or malolactic fermentation and were screened for faults by experts, and then were manually bottled in 750 mL green glass bottles with natural corks and stored at 4°C until wine analysis and sensory evaluation.

Wines were analyzed approximately 6 months after bottling. Titratable acidity and pH were measured using the aforementioned methods. Ethanol content was measured using gas chromatography/flame ionizer detector (GC-FID) with 2% butanol as an internal standard, FactorFour TM VF-WAXms column (30mm x 0.25mm x 1.0 µm) with a 1 µm injection with at least a 9:1 split. The injector and detector temperature was at 250°C and the oven was held at 40°C for 4 minutes with a 20°C/min ramp to 250°C which was held for 4 minutes. For measuring organic acids, high performance liquid chromatography (HPLC) was used with a photodiode array detector as described by Castellari et al (2000).

Sensory

Wines from 2011 and 2012 were evaluated for aromatic differences 12 and 6 months after bottling respectively. Wines were sorted by aroma and analyzed using multi-dimensional sorting analysis using the method described by Preszler et al. (Preszler et al. 2013) for Riesling aroma sorting. Aroma sorting was done by a panel consisting of males and females, ages 21 to 63, who were a part of Cornell University faculty, staff, and students who self-reported consuming white wine at least once per month. In 2011 and 2012, 46 and 62 panelists participated respectively in the trials. Participants were seated in a fluorescently lit room and separated by white partitions. Wines were served in served 30 mL portions at room temperature in clear, tulip-shaped

ISO 220 mL wine glasses with aluminum foil lids. Two replicates of each under-vine treatment were served, so a total of eight glasses coded with a random 3-digit unique identification number were presented to panelists in a randomized order. Panelists were asked to sort wines, by aroma only without tasting, into 1 to 4 groups, placing wines that were found to be similar by aroma together. Panelists were instructed to sort wines based on their perceptions of the aromatic properties, using their own sorting criteria. Panelists did not receive any advance training and there was no rating of wine characteristics, to reduce imposed researcher bias and in accordance with past research (Lawless and Heymann; Preszler et al. 2013).

Statistics

All vineyard and juice characteristic data was analyzed using JMP 11 (SAS Institute, Cary, NC) using a mixed model ANOVA, with treatment as a fixed variable and replicate number as random. Significance was determined using the Tukey HSD test at a 5% significance level.

To analyze sorting results, wines that were grouped together were given a similarity rating of one and wines not sorted into the same group scored a zero. The sum of the similarity scores for each pair of samples was calculated and similarity square matrix for each vintage created and analyzed using multidimensional scaling (MDS) statistical analysis (Kruskal 1964) using SAS (Version 8.0, Cary, NC). MDS generates a visual representation of the similarity square matrix, where samples that were paired together more often are closer spatially and those that were not grouped together were farther apart. The resulting graphical output of the MDS analysis can be used to interpret similarity among samples, even when the underlying attributes are not exactly known (Lawless and Heymann 1988). MDS has been previously used for food science studies (Lawless and Heymann 1998; Lawlesss and Glatter 1990) and specifically white wine aroma evaluation (Lee and Noble 2006; Preszler et al. 2013).

Results

Cover Crop Establishment

Cover crops were successfully established in each year of the study while the glyphosate sprayed control remained bare of vegetation (Figure 2.1).

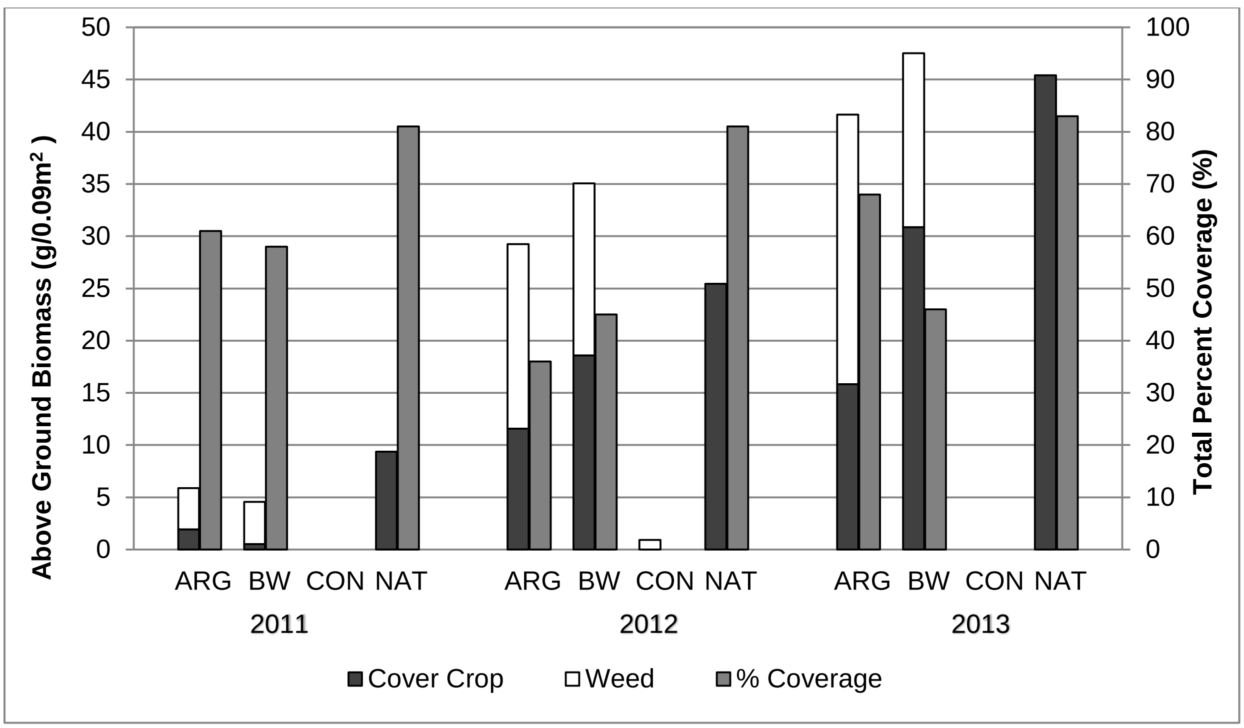

Figure 2.1. Above ground biomass of cover crop and weeds after mowing and percent total coverage of vegetation taken from under-vine rows of Riesling grapevines in the Finger Lakes, NY from 2011 to 2013 at veraison. Treatment abbreviations: ARG: Annual rye grass; BW: Buckwheat; CON: Glyphosate sprayed control; NAT: Natural vegetation.

In 2011, measurements of biomass were taken after mowing had occurred, resulting in significantly less above ground biomass than was seen in 2012 and 2013 (Figure 2.1). However, the reduced biomass did not affect the percent coverage. NAT consistently had the greatest coverage, with at least 50% ground coverage in all three years of under-vine cover crop establishment. The species comprising the NAT treatment were identified at veraison and harvest each year (Table 2.1). Cover crops were successfully established in each year of the study while the glyphosate sprayed control remained bare of vegetation.

The biomass of cover crops increased every successive year of establishment. Weeds contributed ≥15% of the total above ground vegetative biomass of BW and ARG treatments in all years. Even in the third year of establishment, weeds comprised almost double the biomass than that of the ARG treatment.

Table 2.1. Weed species identified in “natural vegetation” under-vine treatments at veriason and harvest

2011		2012		2013	
Veraison	**Harvest**	**Veraison**	**Harvest**	**Veraison**	**Harvest**
Smooth crabgrass (Digitaria ischaemum Schredb.)	Smooth crabgrass (Digitaria ischaemum Schredb.)	Smooth crabgrass (Digitaria ischaemum Schredb.)	Smooth crabgrass (Digitaria ischaemum Schredb.)	Smooth crabgrass (Digitaria ischaemum Schredb.)	Smooth crabgrass (Digitaria ischaemum Schredb.)
Lady’s thumb (Persicaria maculosa L.)	Large crabgrass (Digitaria sanguinalis L.)	Lady’s thumb (Persicaria maculosa L.)	Large crabgrass (Digitaria sanguinalis L.)	Pensylvania smartweed (Polygonum pensylvanicum L.)	Large crabgrass (Digitaria sanguinalis L.)
Pensylvania smartweed (Polygonum pensylvanicum L.)	Goosegrass (Eleusine indica (L.) Gaertn.)	Pensylvania smartweed (Polygonum pensylvanicum L.)	Annual bluegrass (Poa annua L.)	Common purslane (Portulaca oleracea L.)	Annual bluegrass (Poa annua L.)
Common purslane (Portulaca oleracea L.)	Prostrate spurge (Euphorbia maculata L.)	Common purslane (Portulaca oleracea L.)	Lady’s thumb (Persicaria maculosa L.)	Yellow foxtail (Setaria pumilia (Poir.) Roem. & Schult.)	Lady’s thumb (Persicaria maculosa L.)
	Yellow toadflax (Persicaria maculosa L.)	Yellow foxtail (Setaria pumilia (Poir.) Roem. & Schult.)	Pensylvania smartweed (Polygonum pensylvanicum L.)		Pensylvania smartweed (Polygonum pensylvanicum L.)
	Annual bluegrass (Poa annua L.)	Green foxtail (Setaria virids (L.) P.Beauv.)	Common purslane (Portulaca oleracea L.)		Common purslane (Portulaca oleracea L.)
	Lady’s thumb (Persicaria maculosa L.)	Common lambsquarters (Chenopodium album L.)	Yellow foxtail (Setaria pumilia (Poir.) Roem. & Schult.)		Common lambsquarters (Chenopodium album L.)
	Pennsylvania smartweed (Polygonum pensylvanicum L.)	Fall panicum (Panicum dichotomiflorum Michx.)	Green foxtail (Setaria virids (L.) P.Beauv.)		Yellow foxtail (Setaria pumilia (Poir.) Roem. & Schult.)
	Common purslane (Portulaca oleracea L.)		Common lambsquarters (Chenopodium album L.)		
	Sheep sorrel (Rumex acetosella L.)		Witchgrass (Panicum capillare L.)		
	Yellow foxtail (Setaria pumilia (Poir.) Roem. & Schult.)				
	Dandelion (Taraxacum offincinale F.H. Wigg)				

Soil Characteristics

Table 2.2. Soil properties and Morgan extractable nutrient concentrations from under-vine rows after the third year of under-vine treatment establishment in a Riesling vineyard in the Finger Lakes, NY.

Treatment	Organic Matter (%)	Wet Aggregate Stability	NO_3 (ppm)	P (ppm)	K (ppm)
ARG	6.63 a	41.7 a	0.88 b	21.20 a	136.02 a
BW	6.74 a	39.5 a	1.21 ab	22.37 a	128.03 a
CON	5.91 a	47.1 a	1.91 a	21.30 a	125.23 a
NAT	6.85 a	44.6 a	0.80 b	24.44 a	148.23 a
P-value	0.3248	0.3918	0.0278	0.62	0.8225
Treatment	**Ca (ppm)**	**Fe (ppm)**	**Mn (ppm)**	**Zn (ppm)**	**Al (ppm)**
ARG	231.95 a	71.98 a	25.66 a	2.97 a	96.79 a
BW	210.44 a	81.07 a	26.31 a	4.11 a	99.59 a
CON	194.56 a	76.71 a	22.72 a	3.02 a	94.51 a
NAT	239.03	84.70 a	28.95 a	3.11 a	101.69 a
P-value	0.6550	0.5077	0.3113	0.4065	0.1494

Treatment abbreviations: ARG: Annual rye grass; BW: Buckwheat; CON: Glyphosate sprayed control; NAT: Natural vegetation. Within each column, treatment means were considered significantly different at $P \leq 0.05$ level and using Tukey HSD test.

BW and NAT treatments were found to reduce soil nitrate content by over 50% compared to the CON treatment. There were no significant differences among treatments for concentrations of P, K, Ca, Mg, Al, Fe, Mn, and Zn (Table 2.2). Organic matter content was found to be high, over 5% for all treatments, and organic matter and wet aggregate stability were not impacted by treatment (Table 2.2).

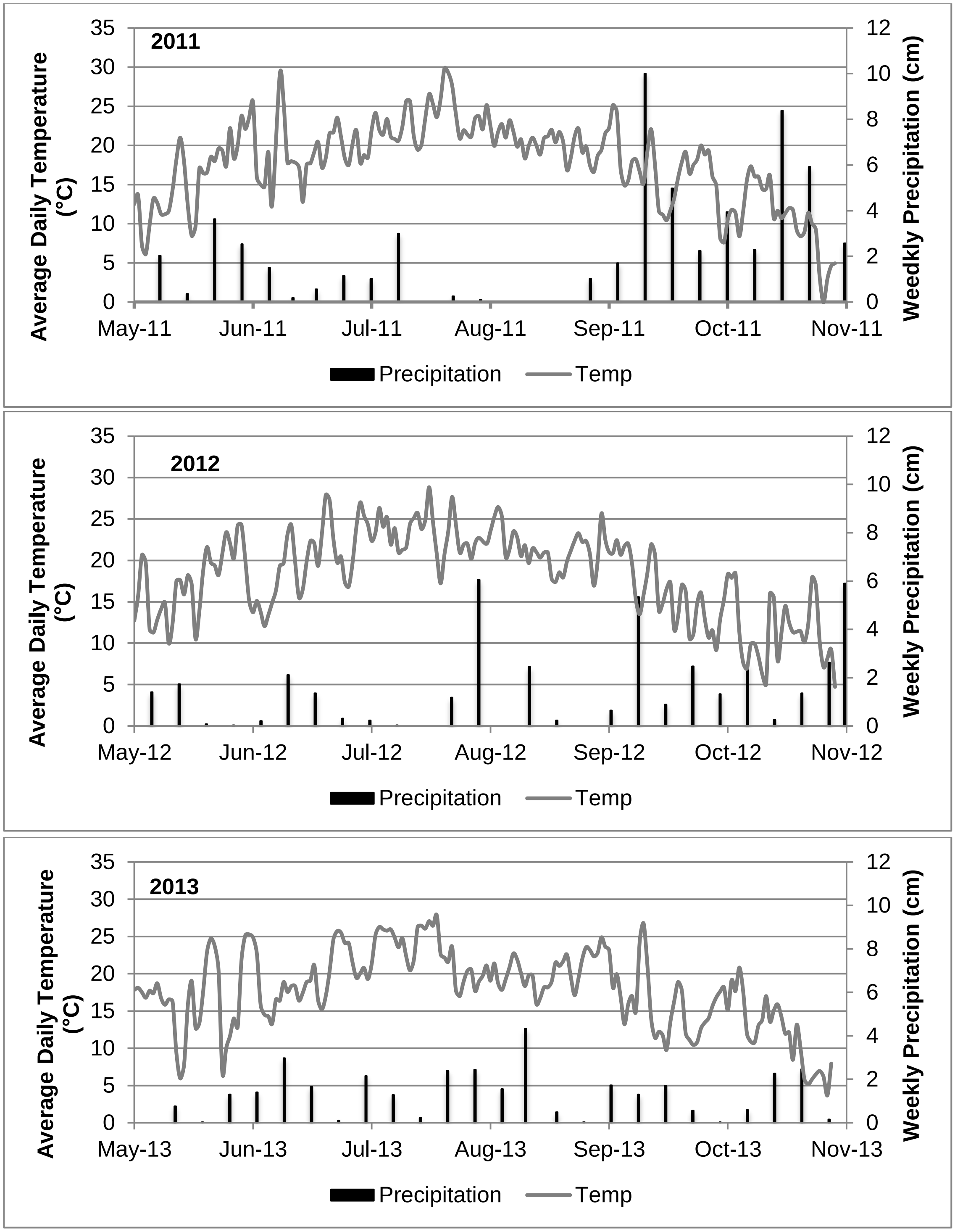

Figure 2.2. Daily average temperature and weekly precipitation from Lodi, NY within 3km of the field research site from 2011-2013. Data accessed from New York State Environmental Applications (NYS IPM Program/Network for Environment and Weather Applications 2009).

Climate

The daily average temperature and weekly precipitation in Lodi, NY within 3 km of the field research site were measured from 2011-2013 (Figure 2.2). The greatest number of growing degree days (2909.3) were accumulated in 2012 compared to 2011 (2791) and 2013 (2792). Total precipitation from 1 May to 31 October was 59.3 cm in 2011, 40.6 cm in 2012, and 34.5 cm in 2013 (NYS IPM Program/Network for Environment and Weather Applications 2009).

Vine Water Potential

To evaluate the soil moisture in the rooting zone, predawn leaf water potential was quantified on three dates in 2012 and two dates in 2013. Under-vine cover crops did not affect predawn leaf water potential with the exception on 6 July 2013 where CON predawn water potential was found to be 0.04 MPa less than BW (Table 2.3). In both 2012 and 2013, predawn water potential values never exceeded -0.30 MPa. Treatments did not impact midday stem water potential of vines (Table 2.3). Midday stem water potential never exceeded -0.6 MPa at any point in either season for any treatments in the study

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Table 2.3. Predawn leaf water potentials ($\Psi_{predawn}$) and midday stem water potentials (Ψ_{midday}) of Riesling grapevines in the Finger Lakes, NY in 2012 and 2013 with different under-vine treatments. $\Psi_{predawn}$ measurements were taken between 0330 and 0500 hours Ψ_{midday} measurements were taken ± 1.5 hours of solar noon.

2012 (MPa)

	$\Psi_{Predawn}$ (MPa)			**Ψ_{Midday} (MPa)**					
Treatment	**11 Jun**	**10 Jul**	**12 Aug**	**11 Jun**	**2 Jul**	**10 Jul**	**2 Aug**	**12 Aug**	**13 Sep**
ARG	-0.28 ± 0.03 a	-0.17 ± 0.02 a	-0.17 ± 0.03 a	-0.55 ± 0.05 a	-0.46 ± 0.03 a	-0.49 ± 0.05 a	-0.46 ± 0.04 a	-0.46 ± 0.06 a	-0.57 ± 0.07 a
BW	-0.29 ± 0.03 a	-0.20 ± 0.02 a	-0.16 ± 0.03 a	-0.55 ± 0.05 a	-0.49 ± 0.03 a	-0.54 ± 0.05 a	-0.48 ± 0.04 a	-0.39 ± 0.06 a	-0.51 ± 0.07 a
CON	-0.27 ± 0.03 a	-0.15 ± 0.02 a	-0.14 ± 0.03 a	-0.55 ± 0.05 a	-0.47 ± 0.03 a	-0.40 ± 0.05 a	-0.39 ± 0.04 a	-0.32 ± 0.06 a	-0.50 ± 0.07 a
NAT	-0.29 ± 0.03 a	-0.18 ± 0.02 a	-0.17 ± 0.03 a	-0.50 ± 0.05 a	-0.45 ± 0.03 a	-0.51 ± 0.05 a	-0.47 ± 0.04 a	-0.36 ± 0.06 a	-0.57 ± 0.07 a
P-value	0.98	0.22	0.89	0.89	0.61	0.24	0.45	0.38	0.87

2013 (MPa)

	$\Psi_{Predawn}$ (MPa)		**Ψ_{Midday} (MPa)**				
Treatment	**6 Jul**	**11 Aug**	**6 Jul**	**21 Jul**	**11 Aug**	**20 Aug**	**18 Sep**
ARG	-0.10 ± 0.01 ab	-0.24 ± 0.03 a	-0.36 ± 0.03 a	-0.36 ± 0.03 a	-0.38 ± 0.03 a	-0.48 ± 0.04 a	-0.53 ± 0.07 a
BW	-0.12 ± 0.01 b	-0.21 ± 0.03 a	-0.32 ± 0.03 a	-0.35 ± 0.03 a	-0.39 ± 0.03 a	-0.48 ± 0.04 a	-0.49 ± 0.07 a
CON	-0.08 ± 0.01 a	-0.17 ± 0.03 a	-0.36 ± 0.03 a	-0.34 ± 0.03 a	-0.37 ± 0.03 a	-0.42 ± 0.04 a	-0.48 ± 0.07 a
NAT	-0.11 ± 0.01 ab	-0.22 ± 0.03 a	-0.33 ± 0.03 a	-0.37 ± 0.03 a	-0.36 ± 0.03 a	-0.45 ± 0.04 a	-0.53 ± 0.07 a
P-value	0.046	0.47	0.73	0.91	0.81	0.68	0.90

Treatment abbreviations: ARG: Annual rye grass; BW: Buckwheat; CON: Glyphosate sprayed control; NAT: Natural vegetation. Analysis of variance was conducted using a mixed model in JMP. For each sampling date, treatment means were considered significantly different at $P \leq 0.05$ level and using Tukey HSD test

Table 2.4. Nutrient analysis of petioles collected at veraison from Riesling grapevines with different under-vine treatments.

Under-vine Treatment	Nitrogen (%)			Phosphorus (%)			Potassium (%)			Magnesium (%)		
	2011	2012	2013	2011	2012	2013	2011	2012	2013	2011	2012	2013
ARG	0.50	0.55	0.43	0.31	0.47 a	0.53	2.14	1.30	2.74	0.57	0.70	0.49
BW	0.57	0.54	0.45	0.29	0.33 b	0.53	2.34	1.20	2.43	0.56	0.71	0.37
CON	0.59	0.55	0.48	0.40	0.33 b	0.50	2.21	1.25	2.24	0.58	0.64	0.46
NAT	0.50	0.54	0.45	0.33	0.37 ab	0.53	1.72	1.09	1.94	0.58	0.65	0.39
P-value	---	0.9602	0.3225	---	0.016	0.796	---	0.7940	0.259	---	0.6024	0.1345

Under-vine Treatment	Aluminum (ppm)			Sodium (ppm)			Calcium (%)			Manganese (ppm)		
	2011	2012	2013	2011	2012	2013	2011	2012	2013	2011	2012	2013
ARG	35.2	222	20.7	239	327	307	1.97	3.14 a	2.02	475	471	591
BW	23.3	221	22.4	244	330	304	2.04	2.91 b	1.92	354	351	971
CON	24.2	223	20.3	221	318	337	2.33	3.03 ab	1.65	344	524	1030
NAT	24.0	218	18.9	253	314	335	2.06	3.12 a	1.98	384	388	789
P-value	--	0.7718	0.0912	---	0.272	0.408	--	0.019	0.054	--	0.4557	0.4035

Under-vine Treatment	Iron (ppm)			Copper (ppm)			Zinc (ppm)			Boron (ppm)		
	2011	2012	2013	2011	2012	2013	2011	2012	2013	2011	2012	2013
ARG	35.5	45.4 a	41.7	2.66	5.67	5.70	46.9	42.5	44.5	32.0	32.4	33.8
BW	16.7	32.3 ab	51.1	2.35	5.76	5.76	34.3	43.5	36.4	31.1	31.1	32.0
CON	NA	25.8 b	43.3	2.71	5.52	5.51	39.8	48.0	35.9	30.0	31.3	31.1
NAT	25.5	38.3 ab	61.1	2.77	5.73	5.89	40.0	46.9	35.7	32.5	30.5	29.9
P-value	---	0.0545	0.255	---	0.81	0.95	--	0.583	0.451	--	0.2000	0.2343

Treatment abbreviations: ARG: Annual rye grass; BW: Buckwheat; CON: glyphosate sprayed control; NAT: Natural vegetation. Analysis of variance was conducted using a mixed model in JMP. For each sampling date, treatment means were considered significantly different at $P \leq 0.05$ level and using Tukey HSD test.

Table 2.5. Shoot lengths and growth rates of Riesling grapevines in the Finger Lakes, NY from 2012 to 2013. Under-vine cover crop and herbicide control treatments were established at the beginning of the growing season of each year and four shoots were flagged for each vine within an experimental unit and measured until hedged. Growth rates were calculated from measured shoot lengths.

2012

	Shoot Length (cm)			**Shoot Growth Rate (cm/day)**	
Treatment	6 Jun	10 Jul	31 Jul	6 Jun –10 Jul	10 Jul – 31 Jul
ARG	42.1 ± 2.9	64.5 ± 5.3	63.0 ± 5.4	0.77 ± 0.06 a	0.14 ± 0.09 a
BW	43.5 ± 3.0	64.4 ± 5.5	66.5 ± 5.4	0.77 ± .07 a	0.09 ± 0.09 a
CON	38.8 ± 2.9	56.2 ± 5.3	61.1 ± 5.4	0.68 ± 0.06 a	0.28 ± 0.09 a
NAT	45.8 ± 2.9	67.5 ± 5.5	62.9 ± 5.8	0.82 ± 0.07 a	0.12 ± 0.10 a
P-value	0.4259	0.3097	0.9090	0.3149	0.2381

2013

	Shoot Length (cm)					**Shoot Growth Rate (cm/day)**			
Treatment	12 Jun	20 Jun	28 Jun	7 Jul	19 Jul	12 Jun – 20 Jun	20 Jun – 28 Jun	28 Jun – 7 Jul	7 Jul – 19 Jul
ARG	39.2 ± 5.0	50.2 ± 6.1	63.8 ± 7.9	73.2 ± 10.1	69.6 ± 7.7	1.67 ± 0.27 a	2.00 ± 0.38 a	0.95 ± 0.32	0.61 ± 0.18 a
BW	38.9 ± 5.0	49.6 ± 6.1	63.9 ± 7.9	71.3 ± 9.6	56.5 ± 7.4	1.45 ± 0.26 a	2.13 ± 0.37 a	0.96 ± 0.27	0.38 ± 0.15 a
CON	43.0 ± 5.0	50.1 ± 6.1	62.7 ± 8.0	72.9 ± 9.7	64.36± 7.6	1.26 ± 0.26 a	2.09 ± 0.35 a	1.22 ± 0.27	0.53 ± 0.15 a
NAT	50.9 ± 5.0	62.7 ± 6.1	64.3 ± 8.2	87.5 ± 10.0	81.9 ± 8.1	1.47 ± 0.25 a	2.78 ± 0.37 a	1.61 ± 0.30	0.74 ± 0.18 a
P-value	0.3276	0.3997	0.6662	0.6409	0.14	0.7398	0.4664	0.3487	0.4664

Treatment abbreviations: ARG: Annual rye grass; BW: Buckwheat; CON: Glyphosate sprayed control; NAT: Natural vegetation. Values are an average of 28-48 shoots ± SE for each date range column. Analysis of variance was conducted using a mixed model in JMP. Within date range columns, treatment means that are followed by the same letter are not significantly different at $P \leq 0.05$ level using Tukey HSD test

Table 2.6. Enhanced Point Quadrant Analysis (EPQA) characteristics of Riesling grapevines with different under-vine treatments for 2011-2013 measured at veraison.

Treatment	Leaf Layer #			% Interior Leaves			% Interior Clusters			Occlusion Layer #		
	2011	2012	2013	2011	2012	2013	2011	2012	2013	2011	2012	2013
ARG	1.90	2.03	1.79	25.12	32.69	30.10	51.60	69.17	45.44	2.71	2.72	2.71
BW	1.95	2.18	1.75	26.19	31.18	24.83	54.38	68.85	45.22	2.81	3.17	2.76
CON	2.14	2.36	1.88	29.70	35.36	32.20	56.93	69.12	50.90	2.97	3.46	2.96
NAT	2.03	2.11	1.79	26.87	32.03	27.08	59.90	62.26	48.62	2.94	3.11	2.83
P-value	0.129	0.511	0.746	0.139	0.425	0.188	0.519	0.593	0.777	0.082	0.1813	0.4301

Treatment	Cluster Exposure Layer			Leaf Exposure Layer			Cluster Exposure Flux Availability			Leaf Exposure Flux Availability		
	2011	2012	2013	2011	2012	2013	2011	2012	2013	2011	2012	2013
ARG	0.60	0.92	0.54	0.26	0.39	0.32	0.39	0.15	0.41	0.48	0.38	0.46
BW	0.58	0.86	0.51	0.29	0.36	0.27	0.30	0.19	0.37	0.42	0.33	0.45
CON	0.65	0.93	0.61	0.32	0.41	0.35	0.24	0.18	0.31	0.38	0.34	0.39
NAT	0.68	0.79	0.55	0.29	0.36	0.31	0.33	0.19	0.34	0.44	0.38	0.43
P-value	0.564	0.554	0.640	0.190	0.596	0.337	0.947	0.928	0.400	0.057	0.608	0.082

Treatment abbreviations: ARG: Annual rye grass; BW: Buckwheat; CON: Glyphosate sprayed control; NAT: Natural vegetation. Values are an average of 4 experimental units for each column consisting of a weighted average by cluster count for the upper and lower fruiting zones of four vines in 2011 and 2012 and two vines in 2013. Analysis of variance was conducted using a mixed model in JMP.

Table 2.7. Yield component and juice characteristic measures of Riesling grapevines with different under-vine treatments for 2011-2013.

Under-vine Treatment	Clusters per Vine 2011	Clusters per Vine 2012	Clusters per Vine 2013	Yield per Vine (kg) 2011	Yield per Vine (kg) 2012	Yield per Vine (kg) 2013
ARG	98.28 ± 4.81 a	75.50 ± 6.27 a	77.5 ± 5.77 a	10.20 ± 0.85 a	7.23 ± 0.87 a	6.85 ± 1.09 a
BW	88.38 ± 4.49 a	77.14 ± 6.39 a	86.50 ± 5.77 a	9.64 ± 0.79 a	8.93 ± 0.90 a	7.82 ± 1.09 a
CON	94.31 ± 4.49 a	86.75 ± 6.27 a	89.00 ± 5.77 a	10.65 ± 0.79 a	9.66 ± 0.87 a	8.43 ± 1.09 a
NAT	88.63 ± 4.65 a	79.75 ± 6.27 a	85.38 ± 5.77 a	9.63 ± 0.82 a	9.04 ± 0.87 a	9.84 ± 1.09 a
P-value	0.41	0.34	0.48	0.77	0.12	0.15

Under-vine Treatment	Cluster Weight (g) 2011	Cluster Weight (g) 2012	Cluster Weight (g) 2013	Shoot Diameter (mm) 2011	Shoot Diameter (mm) 2012	Shoot Diameter (mm) 2013
ARG	118.8 ± 8.08 a	91.9 ± 5.62 b	91.6 ± 8.47 a	8.15 ± 0.18 a	5.81 ± 0.33 a	5.98 ± 0.25 a
BW	124.4 ± 7.63 a	113.5 ± 5.81 a	97.6 ± 8.32 a	7.97 ± 0.20 a	6.53 ±0.33 a	5.50 ± 0.25 a
CON	128.8 ± 7.63 a	111.1 ± 5.62 ab	97.4 ± 8.09 a	8.44 ± 0.18 a	5.50 ± .37 a	5.89 ± 0.25 a
NAT	124.1 ± 7.86 a	110.8 ± 5.62 ab	116.1 ± 7.40 a	8.13 ± 0.18 a	5.91 ± 0.64 a	6.13 ± 0.25 a
P-value	0.83	**0.03**	0.12	0.35	0.69	0.31

Under-vine Treatment	Pruning Weight per Vine (kg) 2011	Pruning Weight per Vine (kg) 2012	Pruning Weight per Vine (kg) 2013[1]	Ravaz Index (kg/kg) 2011	Ravaz Index (kg/kg) 2012	Ravaz Index (kg/kg) 2013
ARG	1.06 ± 0.14 a	0.77 ± 0.13 a	0.76 ± 0.18 a	10.28 ± 1.05 a	12.87 ± 1.95 a	10.09 ± 1.40 a
BW	1.08 ± 0.14 a	0.80 ± 0.13 a	0.90 ± 0.18 a	10.71 ± 1.05 a	14.22 ± 1.99 a	10.91 ± 1.40 a
CON	1.16 ± 0.14 a	0.73 ± 0.13 a	0.90 ± 0.18 a	10.77 ± 1.02 a	15.70 ± 1.95 a	9.36 ± 1.40 a
NAT	1.13 ± 0.14 a	0.80 ± 0.13 a	1.21 ± 0.18 a	9.31 ± 1.05 a	13.00 ± 1.95 a	8.53 ± 1.40 a
P-value	0.96	0.95	0.35	0.74	0.44	0.65

Under-vine Treatment	Berry Weight (g) 2011	Berry Weight (g) 2012	Berry Weight (g) 2013[1]	Berries per Cluster 2011	Berries per Cluster 2012	Berries per Cluster 2013[1]
ARG	1.67 ± 0.04 a	1.63 ± 0.05 a	1.68	71.17 ± 1.98 a	56.3 ± 2.16 b	50.65 ± 5.49 b
BW	1.69 ± 0.04 a	1.65 ± 0.05 a	1.63	73.46 ± 1.98 a	69.2 ± 2.16 a	54.54 ± 5.49 ab
CON	1.74 ± 0.04 a	1.67 ± 0.05 a	1.68	74.22 ± 1.98 a	66.7 ± 2.16 a	55.57 ± 5.49 ab
NAT	1.73 ± 0.04 a	1.68 ± 0.05 a	1.61	72.19 ± 1.98 a	66.0 ± 2.16 a	70.76 ± 5.49 a
P-value	0.67	0.93	--	0.66	**0.006**	**0.04**

Under-vine Treatment	Soluble Solids (°Brix) 2011	Soluble Solids (°Brix) 2012	Soluble Solids (°Brix) 2013[1]	Titratable Acidity (g/L) 2011	Titratable Acidity (g/L) 2012	Titratable Acidity (g/L) 2013[1]
ARG	16.6 ± 0.31 a	17.1 ± 0.56 a	17.5	6.76 ± 0.32 a	8.23 ± 0.28 a	7.5
BW	16.9 ± 0.31 a	16.4 ± 0.56 a	16.8	6.69 ± 0.32 a	8.02 ± 0.28 a	7.4
CON	16.2 ± 0.31 a	16.4 ± 0.56 a	17.3	7.12 ± 0.32 a	8.33 ± 0.28 a	8.0
NAT	16.5 ± 0.31 a	17.1 ± 0.56	18.0	7.03 ± 0.32 a	8.28 ± 0.28 a	8.5
P-value	0.10	0.72	--	0.69	0.81	--

Under-vine Treatment	pH 2011	pH 2012	pH 2013[1]	Yeast Assimilable Nitrogen (mg/L) 2011	Yeast Assimilable Nitrogen (mg/L) 2012	Yeast Assimilable Nitrogen (mg/L) 2013[1]
ARG	3.31 ± 0.05 a	3.00 ± 0.02 a	2.97	52 ± 10 a	32 ± 7 a	32
BW	3.30 ± 0.05 a	3.03 ± 0.02 a	2.92	50 ± 10 a	35 ± 7 a	47
CON	3.38 ± 0.05 a	2.98 ± 0.02 a	2.90	75 ± 10 a	43 ± 7 a	49
NAT	3.29 ± 0.05 a	2.99 ± 0.02 a	2.95	52 ± 10 a	40 ± 7 a	36
P-value	0.067	0.070	--	0.13	0.64	--

Treatment abbreviations: ARG: Annual rye grass; BW: Buckwheat; CON: Glyphosate sprayed control; NAT: Natural vegetation. Values are an average of four fields replicates ± SE for all measures. Analysis of variance was conducted using a mixed model in JMP. Within year columns, treatment means that are followed by the same letter are not significantly different at $P \leq 0.05$ level using Tukey HSD test.

[1] For 2013, berry weights and Brix, TA, pH and YAN characteristics are the measure of 1 replicate

Vegetative Growth and Yields

Treatments did not impact shoot length or shoot growth rate in 2012 or 2013 (Table 2.5). Under-vine cover crops did not impact EQPA parameters (Table 2.6) in any year of the study.

There were no consistent effects of under-vine cover crop treatments on yield components, shoot diameter, pruning weights, or juice characteristics (Table 2.7). The ARG treatment did reduce cluster size compared to BW by 21.5 g in 2012. In 2012, ARG yielded 9-12 fewer berries per cluster compared to all other treatments and in 2013, ARG reduced average berries per cluster by 20 berries compared to the NAT treatment. The number of clusters and total cluster weight per vine and average individual berry mass were not different among treatments. Soluble solids of juice ranged from 16.2 to 18.0° Brix over three years. Under-vine cover did not impact soluble solids, titratable acidity, pH, or YAN values in 2011 or 2012 and this same trend persisted in single replicate samples taken in 2013.

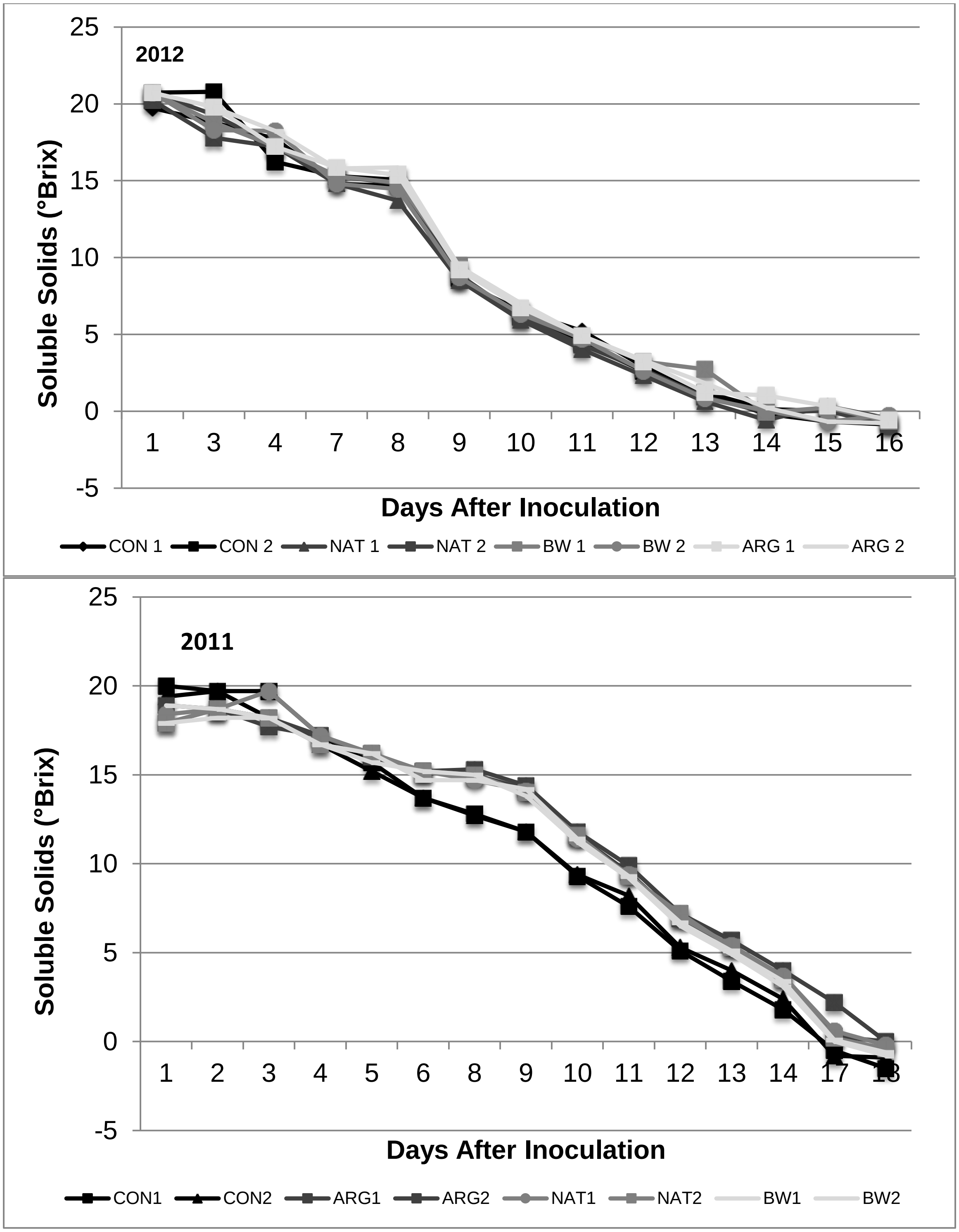

Figure 2.3. Daily monitored soluble solids (°Brix) of fermentations of two five-gallon replicates of Riesling fruit harvested from the following four under-vine treatments: ARG: Annual rye grass; BW: Buckwheat; CON: Glyphosate sprayed control; NAT: Natural vegetation.

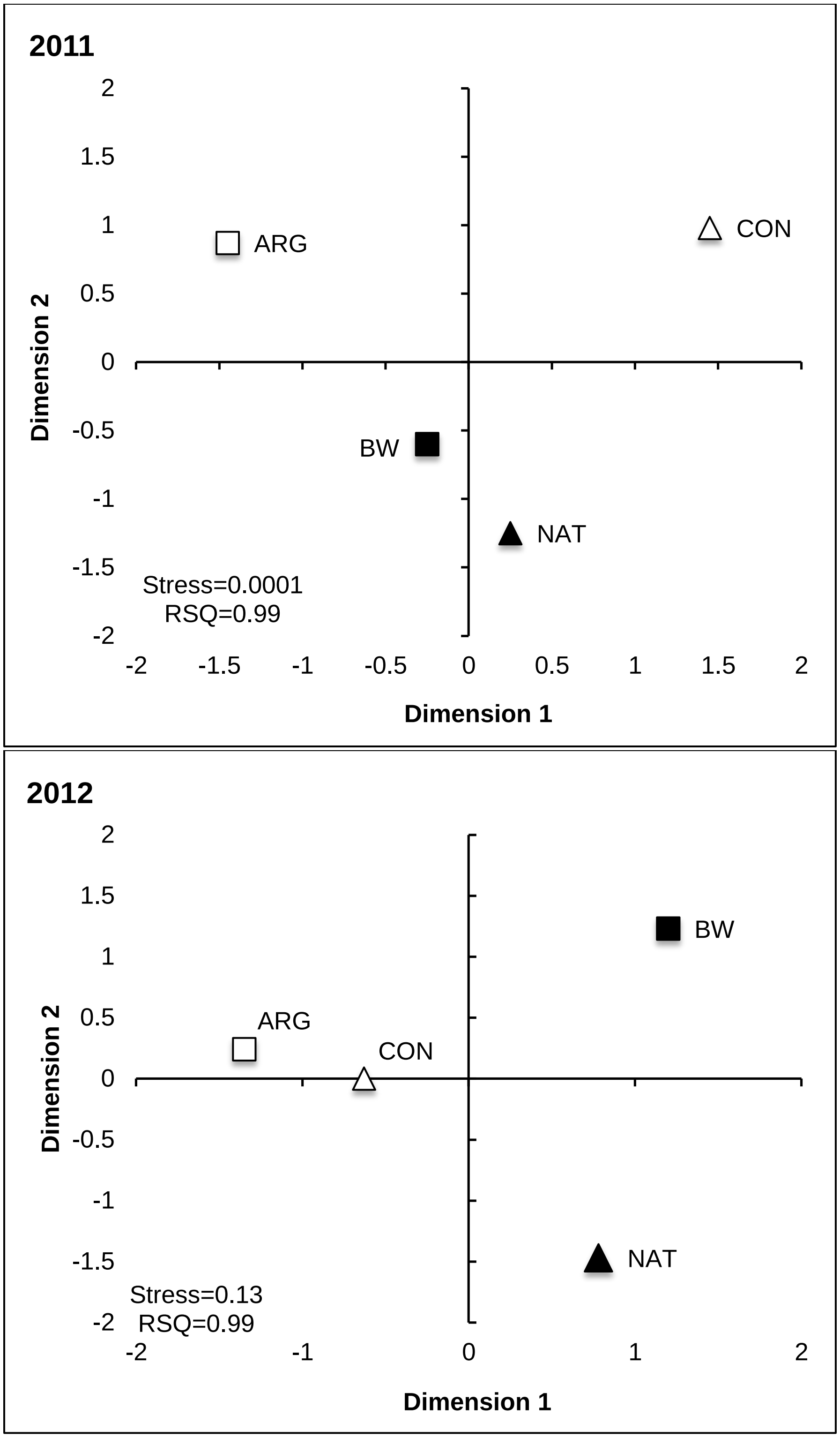

Figure 2.4. Two-dimensional consensus plots of aroma similarity ratings of Riesling wines from 2011 and 2012 from the following under-vine treatments: ARG: Annual rye grass; BW: Buckwheat; CON: Glyphosate sprayed control; NAT: Natural vegetation.

Winemaking and Multi-dimensional Sorting Analysis of Wine Aroma

For each replicate of wine, daily soluble solids readings were taken throughout fermentation (Figure 2.3) and wine analyzed at bottling (Table 2.8).

Table 2.8. Properties of Riesling wine for two five-gallon replicates for each under-vine treatment for 2011 and 2012.

Treatment	**Ethanol (%)**	**TA (g/L)**	**pH**	**Organic Acids (g/L)**				
2011				**Citric**	**Tartaric**	**Malic**	**Lactic**	**Acetic**
ARG (1)	12.79	7.86	2.99	0.15	2.86	2.74	0.00	0.06
ARG (2)	13.60	7.10	3.05	0.15	2.86	2.77	0.00	0.06
BW (1)	12.46	7.83	2.96	0.16	3.19	2.62	0.00	0.08
BW (2)	11.21	7.40	3.03	0.16	3.19	2.58	0.00	0.08
CON (1)	12.59	7.45	3.04	0.17	2.53	3.23	0.00	0.14
CON (2)	13.59	7.35	3.05	0.17	2.56	3.23	0.00	0.14
NAT (1)	10.40	7.99	2.97	0.16	2.97	2.70	0.00	0.09
NAT (2)	13.50	7.53	3.02	0.16	2.98	2.70	0.00	0.09
2012								
ARG (1)	13.19	10.84	3.04	0.18	5.71	2.37	0.54	0.09
ARG (2)	12.57	10.59	3.06	0.18	5.67	2.37	0.54	0.11
BW (1)	12.87	11.03	3.02	0.19	5.93	2.52	0.53	0.10
BW (2)	10.19	10.98	3.03	0.19	5.93	2.51	0.53	0.11
CON (1)	13.23	11.27	2.99	0.20	5.78	2.78	0.54	0.12
CON (2)	13.57	11.45	3.01	0.20	5.74	2.77	0.56	0.12
NAT (1)	12.45	11.01	3.02	0.19	5.88	2.35	0.47	0.15
NAT (2)	12.08	10.72	3.03	0.19	5.83	2.37	0.48	0.16

Treatment abbreviations: ARG: Annual rye grass; BW: Buckwheat; CON: Glyphosate sprayed control; NAT: Natural vegetation. Number in parenthesis denotes replicate number.

A two-dimensional model which met calculated RSQ and stress values criteria was used to create MDS consensus plots which showed that panelists found differences in wine aroma among under-vine cover crop treatments for both years (Figure 2.3). In 2011, all three treatments differed from the control, while BW and NAT were similar. In 2011, ARG and CON were similar in both dimensions, but BW and NAT were found to be different from one another and the CON/ARG grouping.

Discussion

It was hypothesized that annual species of cover crops directly beneath vines would compete with grapevines for water and/or nutrients and result in a reduction in vine vegetative growth. Previous work has demonstrated that reductions in vine vegetative growth and yields with cover crops correlated with reductions in soil and/or vine moisture levels (Lopes et al. 2008; Wheeler et al. 2005). However in this study, the results disproved this hypothesis, since vines never reached the -1.2 MPa soil and -1.6 MPa leaf water potentials necessary to inhibit stomatal conductance (Centeno et al. 2010) and vines were found to be well hydrated at night even when under-vine cover crops were present, never exceeding -0.29 MPa in 2012 and -0.24 MPa in 2013. The water potential values reported in this study are similar to previous values reported for Riesling in the Finger Lakes region (Intrigliolo et al. 2009) and show the lack of water-stressed conditions in Riesling vineyards in some years in the cool Northeastern climate. The cover crops used in this experiment did not generate sufficient competition for water to see any effects on vine water potential or measurable effects on vine vegetative growth or yields.

The species used for cover crops in this study were chosen to introduce competition at different times in the season. Pre-veraison water deficits cause the greatest reductions in measures of vine growth and yields, but the fruit develops a greater insensitivity to water deficits over time (Matthews and Anderson 1989) whereas vine growth will remain responsive to nitrogen supply as the season progresses (Keller 2005). Buckwheat rapidly established and had gone to seed by veraison in this study, but conversely annual rye grass exhibits vigorous growth into the late summer and fall

(Bjorkman and Shail 2010). Natural vegetation established the earliest of all the treatments tested throughout the entire growing season. While largely compromised of Pennsylvania smartweed in the first year, increased species diversity, including the presence of flowering annuals and grasses, occured in the later years and there was successively increased biomass at veraison in each year (Table 2.1). This increase in species diversity also presumably increased the duration of actively growing vegetation beneath the vines compared to the BW and ARG treatments, but this still did not cause significant competition with grapevines to see any growth effects. For a site that had previously used pre-emergent and contact herbicides for weed control, an almost monoculture of Pennsylvania smartweed developed into a diverse ecological system within just two years, indicating that vineyard soils have the ability to maintain cover crop species diversity even after heavy herbicide use if given sufficient recovery time. Further work is needed to understand how the increased diversity gained from natural vegetation could enhance beneficial insect populations or potentially extend the vegetation cover growing period and the potential competition with grapevines.

All of the species tested in this experiment were shallow rooted (Bjorkman and Shail 2010) and grapevines could potentially extend and/or utilize existing roots deeper in the profile to avoid competition. Grapevines are known to have one of the proportionally deepest rooting distributions among plants, and have reported rooting depths of up to 6 meters (Smart et al. 2006). In the Northeast, deep rooting patterns in grapevines have been reported. Root growth was found to occur in the 81-110 cm soil horizon of Northeastern Concord vineyard in two wet years, and non-irrigated vines were found to have slightly greater root production at this deep level than irrigated vines in dry years (Comas et al. 2005). Increasing soil depth is correlated with increasing root survivorship for Concord vines in the Northeast (Anderson et al. 2003), indicating that deep roots will still contribute to water and nutrient transport for longer periods of time in the life of the vine. In this experiment, vines were grafted onto S04 rootstock, and previous research has found that the rooting patterns of S04 rootstock grafted with Cabernet franc were greatly determined by soil type in dry farmed vineyards in the Loire valley, but in all soil types examined, deep roots (>80-90 cm) were present (Morlat and Jacquet 1993). Cover crops restricted vine rooting near the soil surface and encouraged deeper rooting patterns in wine grapes (Morlat and Jacquet 2003). In this study, the deep rooted, non-irrigated SO4 roots of nearly twenty year old vines in a dry farmed Riesling vineyard were likely able to overcome any competition effects from the comparatively shallow root systems of the cover crops due to a well-developed and extensive rooting system that then resulted in no measureable difference in vine water potentials. Previous under-vine cover crop studies in a humid climate that did show a reduction in vegetative growth were conducted on two to four year old vines (Hatch et al. 2011). Newly established vineyards with less developed rooting systems would be more susceptible to the competition effects of vegetation in the vineyard floor.

After three years of establishment, annual species of natural vegetation and annual rye grass were found to reduce soil nitrate concentrations (Table 2.2), but there was no consistent reported effect of cover crops on nutrient content of petiole tissue collected at veraison, including no reduction in nitrogen content (Table 2.4). All treatments including the conventional herbicide spray had lower than recommended values of nitrogen (Wolf 2008), indicating that site conditions were more important to the nutrient status of the vine than any imposed effects by under-vine cover crops.

Similar to several previous studies (Ferrara et al. 2012; Monteiro and Lopes 2007; Pool et al. 1990; Sweet and Schreiner 2010; Tesic et al. 2007), this study found cover crops had no significant impacts on juice characteristics including soluble solids, titratable acidity, pH, and YAN (Table 2.7).

Interestingly, wines produced from vines with the different species of annual under-vine cover crops were found to be different by aroma from each other and those grown with the herbicide control (Figure 2.4) in both years of the study. Previous work has shown that cover-crops can impact compounds important to wine aroma (Reynolds et al. 2005; Xi et al. 2011). Light exposure in the canopy is known to affect aromatics in Riesling. Light response curves have shown that increased canopy shading will decrease concentrations of C13 norisoprenoids like TDN in Riesling (Meyers et al. 2013) and the timing of the light exposure will affect TDN precursors (Kwasniewski et al. 2010). While this study did not detect any differences in cluster or leaf exposure flux availability at veraison (Table 2.6), it is possible the use of under-vine cover crops induced differences in canopy layers and therefore cluster light exposure during the pre-veraison period. Exposure at that time of the season has been reported to increase TDN aroma precursors (Kwasniewski et al. 2010). EPQA measurements were not taken until veraison and therefore would be unable to detect any differences earlier in the season during this critical aromatic development period. Due to the vigorous vine growth seen in in the Northeast, early variances among treatments may have been overlooked as a function of the timing of EPQA data collection.

While no statistically significant differences were found among treatments for midday stem water potentials, differences as little as 0.3 MPa in water potential have been found to result in different juice phenolic concentrations (Matthews and Anderson 1989). While this study found no differences among treatments in stem water potential or measures of vegetative growth, even a slight reduction in available soil moisture, like seen at the one measured predawn value in 2013 (Table 2.3), may have resulted in vine metabolic differences that altered aroma compound precursor production. Similarly, there was no detectable difference in petiole nitrogen content at veraison (Table 2.4), but samples were not collected between budbreak and bloom when developmental demand is highest (Keller 2005). Nitrogen deficiency has been found to decrease wine aroma in the aromatic white wine Sauvignon blanc (Chone et al. 2006). Possibly nitrogen uptake did vary earlier in the growing season and affected aromatic compound synthesis, but by veraison, nitrogen content was low for all treatments due to site conditions and therefore differences were undetectable at that time. Further work to understand how under-vine cover crops may influence the complex timing of water and nutrient availability that impacts aromatic precursor synthesis is needed to better explain the effects seen on wine aroma in this research.

Conclusion

The long-standing practice of using herbicides below vines in the Finger Lakes is derived from the belief that an introduction of vegetation would induce a level of competition that would have a detrimental impact on grapevines, like has been seen in more arid regions. When maintaining high yield is critical to vineyard management, such as in Concord production, herbicide strips have been recommended in order to promote as much vine growth as possible (Pool et al. 1990). However, as growers in cool and humid climates in the American Northeast increasingly plant *V. vinifera* vineyards for the purpose of wine production, conventional practices must be adapted to meet new production goals and ensure the sustainability of winegrowing in the region's future. Over three years, using annual species of under-vine cover crops of buckwheat, natural vegetation, and annual rye grass as an herbicide replacement in under-vine rows did not reduce measures of vine vegetative growth including shoot growth, canopy characteristics, and yield measures at harvest. The results of this study disproved the hypothesis that using three different annual under-vine cover crops would reduce vine growth, therefore grape growers should consider the environmental benefits of replacing conventional herbicide use in mature, vigorous Riesling vineyards in the Northeast with buckwheat, annual rye grass, or natural vegetation, since the results of this study showed that these species in the under-vine rows had little impact on vine vegetative growth, yields, and juice characteristics. However the effects of cover-crop use on wine characteristics should be further studied to be better understood.

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Chapter 3. Evaluating Buckwheat and Chicory as Under-vine Cover Crops in Finger Lakes Riesling

Introduction

There is the potential to damage vineyard soil health by maintaining bare soil directly beneath vines. Herbicide use risks environmental contamination (Dawson et al. 1968; Landry et al. 2006) and cultivation causes soil erosion (Martinez-Casanovas and Sanchez-Bosch 2000). Cover crops may provide a sustainable floor management alternative to conventional herbicide and cultivation use in wine grape vineyards. While it is already commonplace to use interrow cover crops in the cool and humid grape growing regions of the Northeast, bare soil is still traditionally maintained directly beneath vines. In order to promote the elimination of herbicide use on the vineyard floor, there needs to be a better understanding of how cover-crops seeded in the under-vine rows may influence vine growth, yields, and juice characteristics.

Previous work has shown that vine vegetative growth and yields can be reduced when vegetation was maintained in vineyard floor interrows (Lopes et al. 2008; Sweet and Schreiner 2010; Wheeler et al. 2005) and under-vine rows (Hatch et al. 2011; Tesic et al. 2007; Krasnow et al. 2013) in warmer semi-arid and humid climates. Work has shown that the reduction of growth by cover crops can actually be beneifical, bringing pruning weights and yields closer to the appellation mandated requirements (Sicher et al. 1993), closer to the ideal Ravaz index values (Monteiro and Lopes 2007), and improving wine quality (Wheeler et al. 2005; Lopes et al. 2008). Maintaining vegetation directly beneath vines was shown to increase sunlight penetration into the canopy, reduce the number of internal clusters (Tesic et al. 2007) and increasie the cluster and leaf exposure flux availability (Hatch et al. 2011). Reducing shade within the canopy is known to have many beneficial effects, including increased bud fruitfulness and yields, reduced disease, and enhanced fruit composition (Smart 1986).

By expanding cover crop use to under-vine rows, grape growers in the Finger Lakes region could potentially reap the benefits of cover crop use, including decreased herbicide application and increased canopy sunlight exposure from a reduction in vegetative growth. However, in the cool climate of the Northeast, soil must be hilled up over the graft union at the base of vines to ensure scion bud survival, and then the soil must be removed in the spring. These two intensive annual cultivation operations prohibit the establishment of the previously studied perennial, permanent vegetation swards under vines (Hatch et al. 2011; Tesic et al. 2007; Krasnow et al. 2013).

This purpose of this trial was to test the use of annually established cover crops, grown under varying soil moisture conditions using drip-irrigated and dry-farmed conditions, as an herbicide replacement. Three under-vine treatments - a conventional glyphosate strip, annual buckwheat, and perennial chicory – were established on a yearly basis after hilling down in the spring to examine how under-vine cover crop use impacted measures of vine and soil nutrient status, water potential, and vegetative growth, yields, and juice and wine characteristics.

Materials and Methods

Experimental Site

This experiment was established at a Cornell research farm near Lansing, NY on the lower east side of Cayuga Lake (42.57°N, -76.60°W, 124 m elevation). The soil was predominately Hudson-Cayuga silt loam with 12-20% slopes (Soil Survey Staff 1987). Vines of Riesling cl. 9/110 vines on 3309C rootstock were originally planted in 2007 over a pre-existing drainage system in 14 rows on 2.7 m by 1.8 m spacing, with 14 total rows consisting of ten panels. Each panel contained four vines. Vines were trained to a two-tier flat bow system with vertical shoot positioning on two 2.4 m trellis with 0.98 m catch wires. Drip irrigation was installed in a modified split-plot design that delivered water to half of a row, alternating sides of the row throughout the block. Netafim UniRam 16mm inner diameter dripline (Netafim, Fresno, CA) delivered water from 0.1gal/hr (0.38 L/hr) emitters, spaced 40.6 cm apart.

The two outer rows of the block were kept as guard rows and not used for data collection. Each of the three under-vine treatments was applied down the entire length of four randomly selected rows within the block. Five panels, or half of each row, were drip irrigated, and the other half dry farmed. The outermost panels of rows and panels between irrigation treatments were left as buffers. See Fig 3.1.1 for illustration of experimental design.

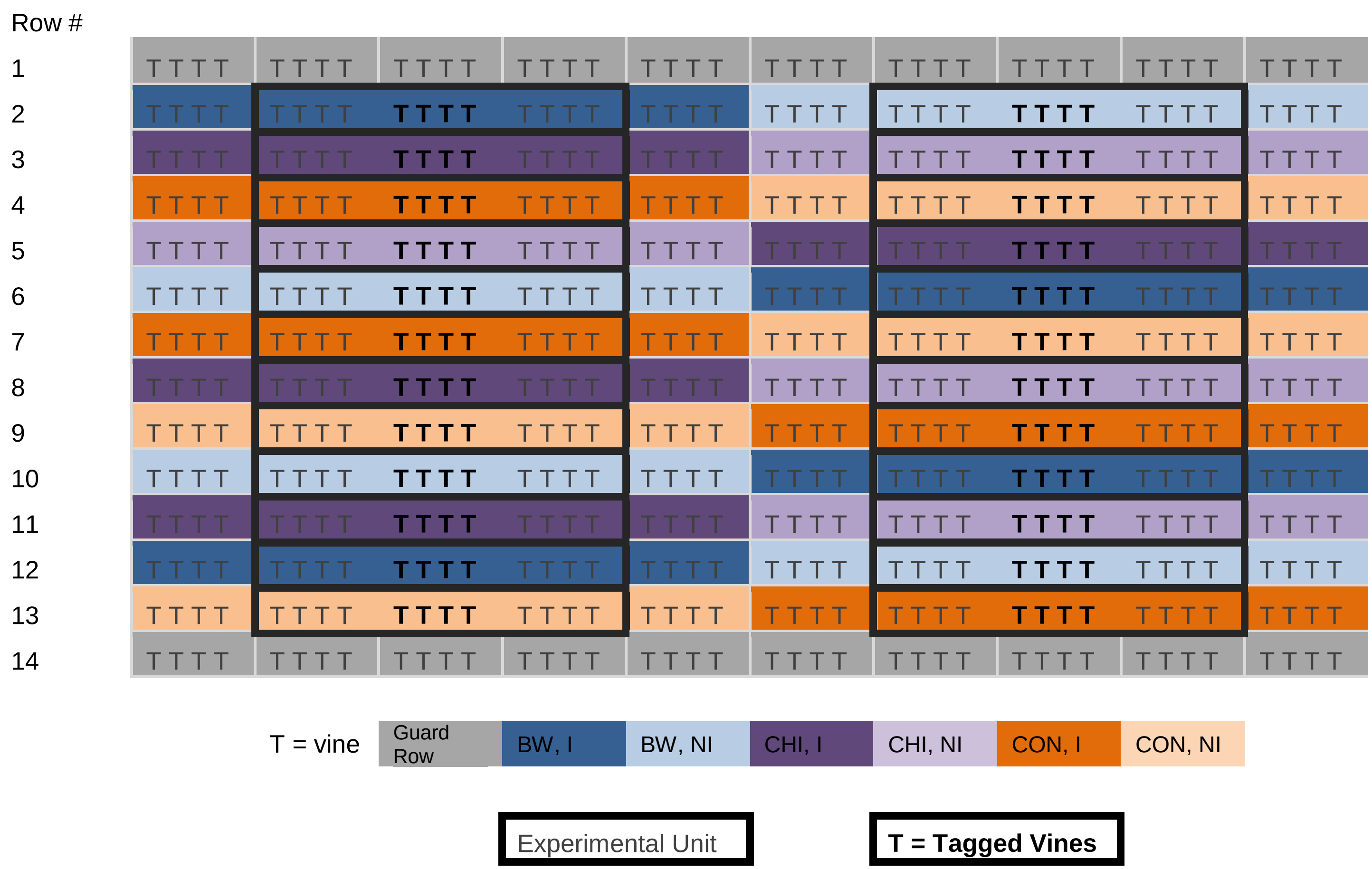

Figure 3.1 Experimental design of Riesling vineyard block at the Cornell Orchards in Lansing, NY.

Under-vine treatments were established on an annual basis in the approximately 1 m wide under-vine row. For rows planted with under-vine cover crops, the top 10 cm of the soil was cultivated by hand, cover crops were then seeded by hand, and the soil gently raked to cover seeds. Chicory (*Cichorium intybus*) was seeded at 5.6 kg/ha in the second week of May in 2012 and 2013 and buckwheat (*Fagopyrum esculentum*) was seeded in under-vine rows at 390 kg/ha in the last week of May in 2012 and 2013 (Earnst Seed Company, Meadville PA). Glyphosate (Roundup® PRO concentrate, Monsanto, St. Louis MO) was applied at 4.7 L/ha on in the first week of June in 2012 and 2013.

Vines were then shoot-thinned to 20 shoots per linear canopy row meter in the first week of June, preferentially removing all secondary and non-fruitful shoots. Vegetative growth was managed throughout the season with vertical shoot positioning. Vines were never hedged, and long shoots were wrapped along the uppermost fruiting wire. Vines were otherwise managed according to standard practices for *Vitis vinifera* plantings in the Finger Lakes region (Wolf 2008).

Within one week of 50% berry veraison by softness each year, rectangular framed areas of 0.09 m^2 were used to estimate percent coverage of the cover crop. For each experimental unit, the frame was used to sample two areas within the 1 m under-vine row. Frames were gridded with string into a total of 160 squares that were 5.6 cm^2 each. Within the frame, each square was visually evaluated for the presence of cover crop or weeds to measure the percent coverage. Above-ground biomass was collected separately for cover crop and weed species, dried at 65°C for 48 hours, and weighed (Santorius ELT103, accuracy ±0.001, Goettingen, Germany).

Each vine was dormant-pruned to four, 12-bud fruiting canes with renewal spurs in late winter. Vines were then shoot-thinned to 20 shoots per linear canopy row meter in spring, preferentially removing all secondary and non-fruitful shoots.

Climate data was sourced from the Network for Environment and Weather Applications from a weather station located at the Cornell Orchards property in Lansing, NY, (42.57°N, -76.60°W, 124 m elevation), within 50 m of the research block.

Soil Testing

Soil was collected in accordance with the Cornell Soil Health Test (Gugino et al. 2009) sampling protocol on 19 October 2013, two weeks after harvest. Within each replicate, three random samples of approximately 250 mL were taken from the top 20 cm of the soil of the under-vine row within each experimental unit. Soil samples were pooled and thoroughly mixed, and dried at 50°C overnight before being submitted for analysis at the Cornell Nutrient Analysis Laboratory (Ithaca, NY) for soil pH and buffer pH, organic matter content from loss on ignition, Morgan extractable nutrient and nitrate concentrations, and wet aggregate stability according to the Cornell Soil Health test.

Vegetative Growth Measures

Pruning Weights

Pruning weights of dormant canes from the previous season from harvested vines was taken in late March each year. Each vine within an experimental unit was dormant-pruned to four 10-bud fruiting canes with renewal spurs and the prunings were weighed on a per vine basis with a hanging scale accurate to 0.01 kg (Salter Brecknell, model SA3N340, Fairmont, MN).

Shoot Lengths

The first week of June after shoot thinning, nine randomly selected fruitful shoots from each experimental unit were flagged. From that time onward, shoot lengths were measured from the base of the shoot to the shoot tip using a flexible metric measuring tape throughout the growing season until the shoot tip was damaged or until 50% berry veraison was reached.

Shoot diameters

At veraison, the internodes of 12 shoots in each experimental unit were randomly selected and measured above the fully developed node using electronic calipers (Kolbat 0.5ft Metric and SAE Caliper, Mooresville NC). For all shoots, to account for oval shapes, two measurements across the larger and smaller radii of the shoot width were taken and averaged for the reported cane diameters.

Enhanced Point Quadrat Analysis

At 50% veraison, the canopy architecture was quantified using the point quadrat analysis (PQA) method described by Smart and Robinson (Smart and Robinson 1991) and the enhanced point quadrat analysis (EPQA) functions published by Meyers and Vanden Heuvel (Meyers and Heuvel 2008). For tagged vines within each experimental unit, canopy probe insertion measurements were taken every 20 cm along the horizontal fruiting zone of the canopy. Photosynthetic photon flux measurements to quantify canopy light interception were taken within 2 days of PQA measurements using a ceptometer (Decagon, model AccuPAR LP-80, Pullman, WA) ±1.5 hours of solar noon on a clear day. For each data panel, the intracanopy photon flux was measured by holding the ambient flux sensor in the unshaded row-middle, while placing the ceptometer parallel to the row within the center of the canopy in the fruiting zone at the height fruiting wire. Ten measurements were taken and averaged for calculating canopy light interception characteristics for each vine (Meyers and Heuvel 2008).

Shoot Tip Activity Rating

When 50% of berries were detected by softness to have initiated veraison in 2012, 60 randomly selected shoots within each experimental unit were evaluated for shoot tip activity using the binary rating and evaluation system described by Hatch et al. (Hatch et al. 2011). If shoot tips had aborted or were beneath the height of adjacent young leaves and had stopped elongating, a score of “0” was given. If shoot tips were intact, above the height of young leaves, and still elongating, a score of “1” was given. Shoot tip activity was then the resulting average of these binary scores. Shoot tips were not evaluated in 2013 due to excessive downy mildew damage.

Vine Water Potential

Predawn leaf water potential ($\Psi_{predawn}$) measurements were taken approximately once a month during the growing season. Measurements were taken between 0330 and 0500 hours using a Scholander pressure chamber (Plant Water Status Console 3000, Soil Moisture Equipment Corp., Santa Barbra, CA, USA). Leaves were enclosed in a 250 cm^2 plastic bag and then cut at the petiole with a razor blade and inserted into the pressure chamber in ten seconds or less. The chamber was then pressurized with nitrogen gas at approximately a rate of 0.1 MPa/sec until xylem sap was witnessed to be exuded from the cut petiole cross section. This pressure was multiplied by -1 to get the $\Psi_{predawn}$ of the vine.

Midday stem water potential (Ψ_{midday}) measurements were taken throughout the growing season within ±1.5 hours of solar noon using the pressure chamber described above. Healthy, well-exposed leaves were enclosed within aluminum foil covered, 250 cm^2 plastic bags for one hour before Ψ_{midday} measurements were made. Petioles of bagged leaves were then cut with a razor blade and inserted into the pressure chamber in ten seconds or less and the chamber was pressurized with compressed nitrogen gas at approximately a rate of 0.1 MPa/s until xylem sap was witnessed to be exuded from the cut petiole cross section. This pressure was multiplied by -1 to get the Ψ_{midday} of the vine.

Petiole Nutrient analysis

From within each experimental unit, 100 petioles in 2012 and 2013 were cut from leaf blades and shoots the week of 50% berry veraison. Samples were then gently washed in a mild soap solution, rinsed with deionized water, stored in paper bags, and dried at 90°C for one hour. Samples were then submitted to the Cornell Nutrient Analysis Laboratory for combustion analysis of C and N and dry ash extraction of Al, B, Ca, Cu, Fe, K, Mg, Mo, Mn, Na, P, and Zn.

Harvest and Fruit Composition

At the onset of veraison, 100-berry samples were collected from each treatment replicate approximately twice a week until harvest. After crushing by hand and filtering through cheesecloth, the juice samples were frozen and stored at -20°C until analysis. At harvest, the grapes from each replicate treatment were hand harvested on 19 September 2012 and 9 October 2013. The total number of clusters per vine was counted and the cumulative cluster weight per vine was measured at harvest using a hanging scale (Salter Brecknell, model SA3N340, Fairmont, MN) and subsequent average cluster weight calculated from these values. For each experimental unit, two 100 berry samples were randomly collected and weighed to determine average berry weight and calculate the average number of berries per cluster.

All juice was thawed and warmed in a water bath at 60°C for 30 minutes and allowed to equilibrate to room temperature before analysis of soluble solids, TA, and pH. The soluble solids content was measured using a digital refractometer with temperature compensation (Wilkens-Anderson Company, model ATAGO PAL-1, Chicago, IL for 2012, Leica Inc., Buffalo, NY for 2013) and pH was analyzed using a calibrated pH meter (Fisher Scientific, Accumet Basic AB15, Hampton, NH for 2011 and 2012, VWR SympHony, model SB8OP1, Radnor PA for 2013). Titratable acidity (TA) was measured by titrating 10 mL of juice with 0.10 M NaOH to a pH of an endpoint of 8.2 measured by a pH meter for 2012, and TA was measured by titrating a 50 mL aliquot of juice against 0.10 M NaOH top H 8.2 using an automatic titrator (Mettler Toledo, model DL22, Columbus, OH) for 2013. Juice samples from each experimental unit at harvest were also tested for yeast assimilable nitrogen (YAN) using a Chemwell 2910 Multianalyzer to test for AMM and spectrophotometry for PAN as described by Nisbet et al. (Nisbet et al. 2013).

Winemaking

After harvest, fruit with more than 30% rot as determined by visual inspection was discarded. All remaining fruit from the different replicates for each treatment was combined and refrigerated at 4°C for 24 hours in 2012 before pressing at the New York State Agriculture Experiment Station Vinification and Brewing Laboratory (Geneva, NY). Fruit was destemmed, crushed, and pressed with a basket press. Juice was treated with 50 mg/L of sulfur dioxide as potassium metabisulfite before settling for 24 hours at 4°C. Juice from each of the four treatments was then was racked into two five-gallon glass carboys to produce two wine replicates per treatment. Juice was inoculated with 0.25 g/L of *Saccharomyces cerevisae* strain EC-1118 (Lallemand Inc., Toulouse, France) rehydrated with Go-Ferm as per manufacturer's directions (Lallemand). Carboys were then moved into a 15°C fermentation room and stirred daily. FermAid K (Lallemand) was added in after at the lag phase (approximately 3 days after inoculation) and after 1/3 sugar depletion at 0.15 g/L and diammonium phosphate supplemented after lag-phase to bring the total YAN of juice to 200 ppm total, inclusive of the FermAid K additions. Wines were fermented until dryness and confirmed to contain less than 0.5% residual sugar with Clinitest tablet (Bayer, West Haven, CT). Wines were then racked into clean carboys and stored at 4°C, with 50 mg/L of sulfur dioxide as potassium metabisulfite added. Wines were not subjected to acid adjustments or malolactic fermentation and were screened for faults by the winemaking team, and then were manually bottled in 750 mL green glass bottles with screwcaps and stored at 20°C until wine analysis and sensory evaluation. Wines were analyzed approximately 6 months after bottling. Titratable acidity and pH were measured using the aforementioned methods. For measuring organic acids, high performance liquid chromatography (HPLC) was used with a photodiode array detector as described by Castellari et al (2000).

Sensory

Wine from 2012 was evaluated for aromatic differences 5 months after bottling. Wines were sorted by aroma and analyzed using multi-dimensional sorting analysis using the method described by Preszler et al. (Preszler et al. 2013) for Riesling aroma sorting. Aroma sorting was done by a panel consisting of males and females, ages 21 to 63, who were a part of Cornell University faculty, staff and students who self-reported consuming white wine at least once per month. In 2011 and 2012, 53 panelists participated in the trial. Participants were seated in a fluorescently lit room and separated by white partitions. Wines served 30 mL of wine at room temperature in clear, tulip-shaped ISO 220 mL wine glasses with aluminum foil lids. Two replicates of each under-vine treatment were served, so a total of eight glasses coded with a random 3-digit unique identification number were presented to panelists in a randomized order. Panelists were asked to sort wines, by aroma only without tasting, into at least one but no more than six groups, placing wines that were found to be similar by aroma together within a group and those that they found to be different in separate groups. Panelists were instructed to sort wines based on their perceptions of the aromatic properties, using their own sorting criteria. Panelists did not receive any advance training and there was no rating of wine characteristics, to reduce imposed researcher bias and in accordance with past research (Lawless and Heymann 1998; Preszler et al. 2013).

Statistics

All vineyard and juice characteristic data was analyzed using JMP 10.0.2 (SAS Institute, Cary, NC) using a mixed model ANOVA, with treatment as a fixed variable and irrigation row grouping and row as random variables. Significance was determined using the Tukey HSD test at a 5% significance level.

To analyze sorting results, wines that were grouped together were given a similarity rating of one and wines not sorted into the same group scored a zero. The sum of the similarity scores for each pair of samples was calculated and similarity square matrix for each vintage created and analyzed using multidimensional scaling (MDS) statistical analysis (Kruskal 1964) using SAS (Version 8.0, Cary, NC). MDS generates a visual representation of the similarity square matrix, where samples that were paired together more often are closer spatially and those that were not grouped together were farther apart. The resulting graphical output of the MDS analysis can be used to interpret similarity among samples, even when the underlying attributes are not exactly known (Lawless and Heymann 1998). MDS has been previously used for food science studies (Lawless and Heymann 1998; Lawlesss and Glatter 1990), and specifically white wine aroma evaluation (Lee and Noble 2006; Preszler et al. 2013).

Results

Climate

The daily average temperature and weekly precipitation at the Cornell Orchards in Lansing, NY within 50 m of the field research site was measured from 2012 -2013 (Fig. 3.1). The year 2012 accumulated more growing degree days (2993) compared to 2013 (2787) and was wetter (1 May to 31 October), with the growing season precipitation totaling was cm 52.1 in 2012 with the majority of rain occurring post-veraison, and 43.3 cm in 2013 with the majority of rain occurring pre-veraison.

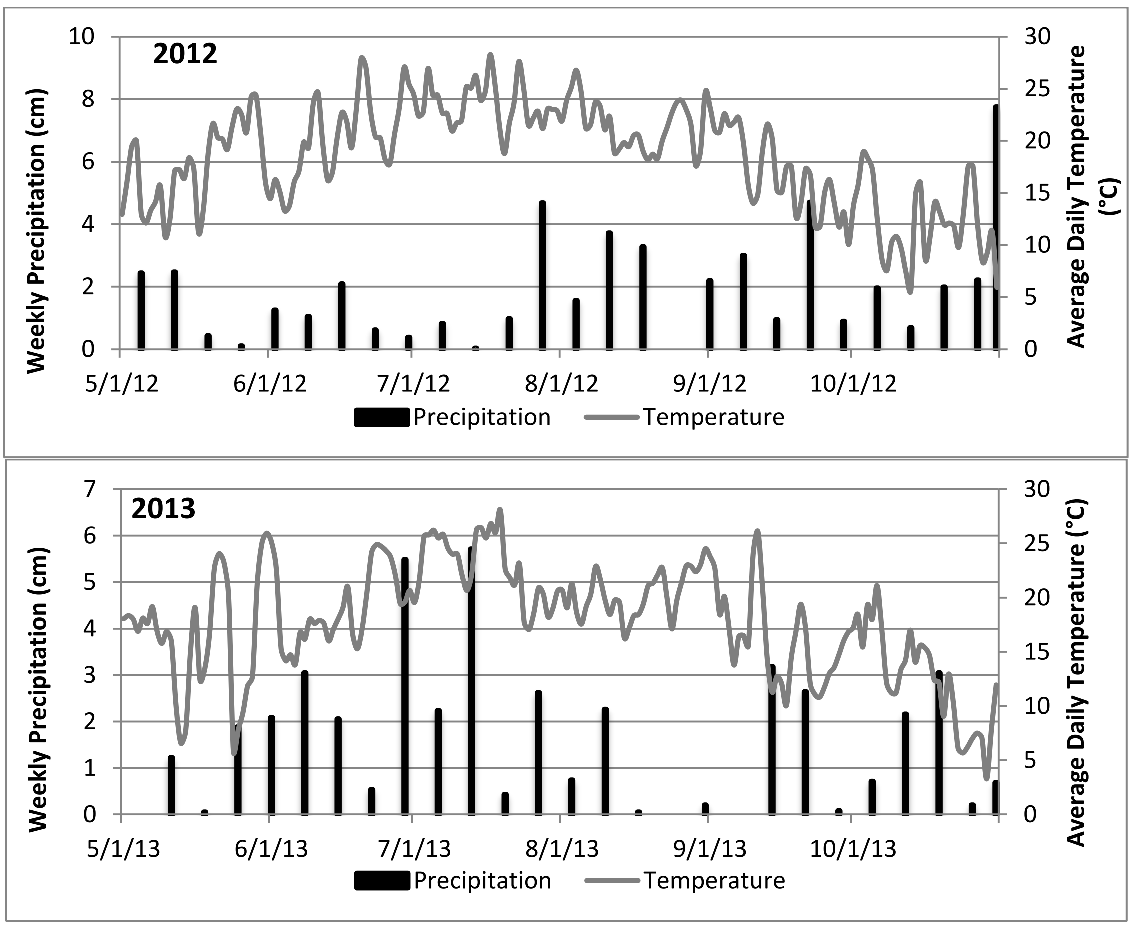

Figure 3.2. Daily average temperature and weekly precipitation from Lansing, NY within 50m of the field research site from 2012-2013. Data accessed from New York State Environmental Applications (NYS IPM Program 2009).

Table 3.1. Morgan extractable nutrient content from soil in the upper 0-20 cm of under-vine rows. Samples were collected in the second year of under-vine cover crop establishment in the late fall of 2013 in a Riesling vineyard in the Finger Lakes, NY.

Treatment	NO_3 (ppm)	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	Al (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)
Cover Crop									
BW	4.74 ±0.67 a	2.19 ± 0.21 a	114.87 ±25.4 a	830.53 ±71.7 a	106.71 ±7.78 a	7.12 ±1.92 a	0.78 ±0.92 a	8.20 ±1.2 a	1.82 ±0.75 a
CHI	4.05 ±0.73 a	2.51 ± 0.23 a	118.61 ±25.8 a	792.66 ±77.4 a	117.95 ±8.40 a	4.99 ±2.02 a	0.58 ±0.13 a	7.66 ±1.9 a	0.94 ±0.81 a
CON	5.27 ±0.68 a	2.13 ± 0.21 a	115.38 ±25.4 a	736 ±71.7 a	106.30 ±7.76 a	6.22 ±1.97 a	0.75 ±0.13 a	7.24 ±1.2 a	1.81 ±0.81a
Irrigation									
IR	4.85 ±0.55 a	2.30 ± 0.17 a	111.81 ±27.2 a	789.26 ±58.5 a	112.42 ±7.87 a	5.12 ±1.22 a	0.61 ±0.13 a	7.52 ±1.04 a	1.35 ±0.61 a
NI	4.53 ±0.58 a	2.26 ± 0.17 a	120.77 ±27.2 a	783.97 ±61.7 a	108.22 ±8.01	7.01 ±1.93 a	0.80 ±0.13 a	7.88 ±1.05 a	1.69 ±0.67 a
Cover Crop x Irrigation									
BW*IR	4.59 ±0.96 a	2.25 ± 0.30 a	118.23 ±28.8 a	849.95 ±101 a	105.08 ±11.0 a	6.09 ±2.16 a	0.71 ±0.15 a	8.08 ±1.45 a	2.25 ±1.06 a
BW*NI	4.91 ±0.96 a	2.13 ± 0.30 a	111.52 ±28.8 a	811.11 ±101 a	108.34 ±11.0 a	8.16 ±2.16 a	0.85 ±0.15 a	8.33 ±1.46 a	1.39 ±1.06 a
CHI*IR	3.74 ±0.96 a	2.36 ± 0.29 a	109.83 ±28.8 a	702.03 ±101 a	126.97 ±11.0 a	4.01 ±2.16 a	0.48 ±0.15 a	7.56 ±1.46 a	1.15 ±1.06 a
CHI*NI	4.37 ±1.11 a	2.67 ± 0.35 a	127.40 ±29.9 a	883.28 ±117 a	108.92 ±12.7 a	5.96 ±2.30 a	0.68 ±0.16 a	7.75 ±1.72 a	0.73 ±1.22 a
CON*IR	6.25 ±0.96 a	2.29 ± 0.30 a	107.37 ±28.8 a	815.80 ±101 a	105.2 ±10.9 a	5.27 ±2.15 a	0.64 ±0.15 a	6.92 ±1.45 a	0.65 ±1.06 a
CON*NI	4.30 ±0.96 a	1.97 ± 0.29 a	123.39 ±28.8 a	657.51 ±101 a	107.4 ±11.0 a	7.17 ±2.16 a	0.86 ±0.15 a	7.57 ±1.47 a	2.96 ±1.23 a
Significance									
Cover Crop	0.4898	0.4650	0.9440	0.6552	0.4484	0.4101	0.2218	0.7582	0.6757
Irrigation	0.6846	0.8515	0.7192	0.9511	0.7173	0.2399	0.2027	0.7519	0.7115
CC X IR	0.3744	0.6226	0.5116	0.2941	0.5051	0.9940	0.8722	0.9835	0.3335

Treatment abbreviations: BW: Buckwheat; CHI: Chicory; CON: Glyphosate sprayed control; IR: Irrigated; NI: Not irrigated. Values are an average of soil samples collected from four experimental units ± SE for all measures. Analysis of variance was conducted using a mixed model in JMP. Within year columns, treatment means that are followed by the same letter are not significantly different at $P \leq 0.05$ level using Tukey HSD test.

Soil Characteristics

There were no significant differences among treatments for soil concentrations of NO_3, P, K, Ca, Mg, Al, Fe, Mn, and Zn (Table 3.1). Additionally no soil characteristics, including pH, buffer pH, organic matter content, or wet aggregate stability, were affected by under-vine treatments (Table 3.2).

Table 3.2. Soil properties from soil in the upper 0-20 cm of under-vine rows after the second year of under-vine cover crop establishment in the late fall of 2013 in a Riesling vineyard in the Finger Lakes, NY.

Under-vine Treatment	pH	Buffer pH	Organic Matter (%)	Wet Aggregate Stability
Cover Crop				
BW	6.05 ± 0.17 a	6.44 ± 0.04 a	3.39 ± 0.19 a	32.5 ± 3.5 a
CHI	6.05 ± 0.17 a	6.46 ± 0.04 a	3.34 ± 0.21 a	39.1 ± 3.8 a
CON	6.08 ± 0.16 a	6.45 ± 0.04 a	3.36 ± 0.19 a	39.3 ± 3.5 a
Irrigation				
IR	6.16 ± 0.15 a	6.46 ± 0.03 a	3.46 ± 0.16 a	38.9 ± 2.9 a
NI	5.98 ± 0.15 a	6.44 ± 0.03 a	3.27 ± 0.17 a	35.0 ± 3.0 a
CC x Irrigation				
BW*IR	6.18 ± 0.19 a	6.44 ± 0.04 a	3.74 ± 0.27 a	34.2 ± 4.9 a
BW*NI	5.92 ± 0.19 a	6.44 ± 0.04 a	3.04 ± 0.27 a	30.8 ± 4.9 a
CHI*IR	6.05 ± 0.19 a	6.47 ± 0.04 a	3.23 ± 0.27 a	42.4 ± 4.9 a
CHI*NI	6.04 ± 0.22 a	6.45 ± 0.04 a	3.46 ± 0.32 a	35.9 ± 5.7 a
CON*IR	6.20 ± 0.19 a	6.47 ± 0.04 a	3.41 ± 0.27 a	40.2 ± 4.9 a
CON*NI	5.98 ± 0.19 a	6.42 ± 0.04 a	3.30 ± 0.27 a	38.4 ± 4.9 a
Significance				
Cover Crop	0.9747	0.8567	0.9868	0.3145
Irrigation	0.3319	0.4502	0.4413	0.3686
CC X IR	0.6379	0.6739	0.2773	0.8983

Treatment abbreviations: BW: Buckwheat; CHI: Chicory; CON: Glyphosate sprayed control; IR: Irrigated; NI: Not irrigated. Values are an average of soil samples collected from four experimental units ± SE for all measures. Analysis of variance was conducted using a mixed model in JMP. Within year columns, treatment means that are followed by the same letter are not significantly different at $P \leq 0.05$ level using Tukey HSD test

Cover Crop Establishment

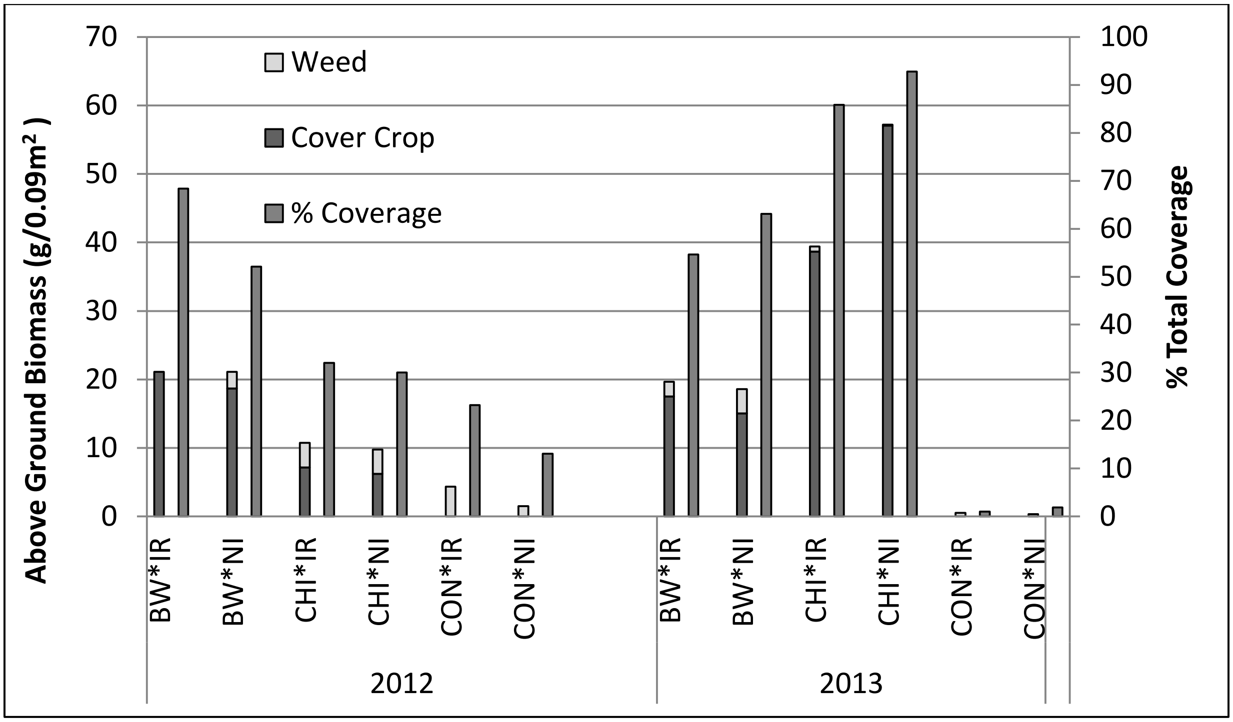

Figure 3.3. Above ground biomass of cover crop and weeds and percent total coverage of vegetation taken from under-vine rows of Riesling grapevines in the Finger Lakes, NY from 2012 to 2013 at veraison. Within a randomly selected $0.09m^2$ area completely within the under-vine row, the total percent of coverage of vegetation was visually estimated and above ground biomass of the cover crop and weeds was collected, dried, and weighed. Treatment abbreviations: BW: Buckwheat; CHI: Chicory; CON: Glyphosate sprayed control; IR: Irrigated; NI: Not irrigated.

Cover crops were successfully established in each year of the study while the glyphosate sprayed control remained bare of vegetation (Figure 3.3). Greater than 45% coverage was maintained for BW and CHI treatments with and without irrigation in both years. The herbicide control exhibited greater weed growth in 2012 than 2013. Coverage of CHI treatment was much greater in the second year of establishment, reflecting the biennial growth habit of chicory and the production of flowering stalks in the second year.

Table 3.3. Predawn leaf water potentials ($\Psi_{predawn}$) and midday stem water potentials (Ψ_{midday}) of Riesling grapevines in the Finger Lakes, NY in 2012 and 2013 with different under-vine treatments.

	2012							
	$\Psi_{Predawn}$ (MPa)		Ψ_{Midday} **(MPa)**					
Treatment	**28 Jun**	**17 Jul**	**28 Jun**	1 Jul	**14 Jul**	**17 Jul**	**29 Jul**	**5 Aug**
Cover Crop								
BW	-0.27 ± 0.04 a	-0.32 ± 0.02 a	-0.71 ± 0.10 a	-0.73 ± 0.05 a	-0.98 ± 0.07 a	-0.80 ± 0.03 a	-0.66 ± 0.03 a	-0.88 ± 0.04 a
CHI	-0.27 ± 0.04 a	-0.35 ± 0.02 a	-0.53 ± 0.08 a	-0.75 ± 0.04 a	-0.92 ± 0.07 a	-0.84 ± 0.03 a	-0.67 ± 0.03 a	-0.92 ± 0.04 a
CON	-0.28 ± 0.04 a	-0.27 ± 0.02 a	-0.64 ± 0.08 a	-0.74 ± 0.05 a	-1.03 ± 0.07 a	-0.77 ± 0.03 a	-0.64 ± 0.03 a	-0.82 ± 0.04 a
Irrigation								
IR	-0.25 ± 0.03 a	-0.29 ± 0.02 a	-0.59 ± 0.07 a	-0.74 ± 0.04 a	-0.92 ± 0.07 a	-0.81 ± 0.03 a	-0.67 ± 0.02 a	-0.88 ± 0.04 a
NI	-0.30 ± 0.03 a	-0.31 ± 0.02 a	-0.67 ± 0.07 a	-0.75 ± 0.04 a	-1.03 ± 0.07 a	-0.79 ± 0.03 a	-0.66 ± 0.02 a	-0.87 ± 0.04 a
CC X IR								
BW*IR	-0.26 ± 0.05 a	-0.33 ± 0.03 a	-0.70 ± 0.11 a	-0.73 ± 0.06 a	-0.94 ± 0.09 a	-0.82 ± 0.04 a	-0.62 ± 0.04 a	-0.91 ± 0.05 a
BW*NI	-0.28 ± 0.05 a	-0.31 ± 0.03 a	-0.71 ± 0.11 a	-0.74 ± 0.06 a	-1.02 ± 0.09 a	-0.77 ± 0.04 a	-0.70 ± 0.04 ab	-0.85 ± 0.05 a
CHI*IR	-0.25 ± 0.05 a	-0.28 ± 0.03 a	-0.43 ± 0.11 a	-0.76 ± 0.06 a	-0.87 ± 0.09 a	-0.83 ± 0.04 a	-0.72 ± 0.04 b	-0.93 ± 0.05 a
CHI*NI	-0.29 ± 0.05 a	-0.35 ± 0.03 a	-0.63 ± 0.11 a	-0.75 ± 0.06 a	-0.96 ± 0.09 a	-0.86 ± 0.04 a	-0.62 ± 0.04 ab	-0.91 ± 0.05 a
CON*IR	-0.25 ± 0.05 a	-0.25 ± 0.03 a	-0.62 ± 0.11 a	-0.73 ± 0.06 a	-0.94 ± 0.09 a	-0.80 ± 0.04 a	-0.64 ± 0.04 ab	-0.81 ± 0.05 a
CON*NI	-0.32 ± 0.05 a	-0.29 ± 0.03 a	-0.65 ± 0.11 a	-0.74 ± 0.06 a	-1.13 ± 0.09 a	-0.74 ± 0.04 a	-0.64 ± 0.04 ab	-0.84 ± 0.05 a
Significance								
Cover Crop	0.9673	0.2482	0.3757	0.9654	0.3244	0.3046	0.6596	0.2916
Irrigation	0.2946	0.3402	0.3572	0.9193	0.2707	0.5046	0.9653	0.6795
CC X IR	0.8640	0.1778	0.2682	0.9640	0.4927	0.5795	**0.0305**	0.7694

	2013							
	$\Psi_{Predawn}$ (MPa)		Ψ_{Midday} **(MPa)**					
Treatment	**13 Jul**	**16 Aug**	**2 Jul**	**13 Jul**	**26 Jul**	**16 Aug**	**21 Aug**	**6 Sep**
Cover Crop								
BW	-0.19 ± 0.02 a	-0.18 ± 0.01 a	-0.26 ± 0.03 a	-0.42 ± 0.03 a	-0.59 ± 0.04 a	-0.47 ± 0.03a	-0.53 ± 0.04 a	-0.32 ± 0.03 a
CHI	-0.21 ± 0.02 a	-0.18 ± 0.01 a	-0.31 ± 0.03 a	-0.45 ± 0.03 a	-0.57 ± 0.04 a	-0.44 ± 0.03 a	-0.53 ± 0.04 a	-0.30 ± 0.03 a
CON	-0.16 ± 0.02 a	-0.16 ± 0.01 a	-0.27 ± 0.03 a	-0.36 ± 0.03 a	-0.53 ± 0.04 a	-0.42 ± 0.03 a	-0.54 ± 0.04 a	-0.24 ± 0.03 a
Irrigation								
IR	-0.18 ± 0.02 a	-0.17 ± 0.01 a	-0.28 ± 0.03 a	-0.39 ± 0.03 a	-0.56 ± 0.03 a	-0.44 ± 0.02 a	-0.52 ± 0.04 a	-0.27 ± 0.03 a
NI	-0.20 ± 0.02 a	-0.18 ± 0.01 a	-0.28 ± 0.03 a	-0.43 ± 0.03 a	-0.57 ± 0.03 a	-0.45 ± 0.02 a	-0.55 ± 0.04 a	-0.31 ± 0.03 a
CC X IR								
BW*IR	-0.19 ± 0.03 a	-0.17 ± 0.02 a	-0.28 ± 0.04 a	-0.45 ± 0.04 b	-0.62 ± 0.05 a	-0.45 ± 0.03 a	-0.55 ± 0.05 a	-0.33 ± 0.04 a
BW*NI	-0.19 ± 0.03 a	-0.18 ± 0.02 a	-0.25 ± 0.04 a	-0.39 ± 0.04 ab	-0.56 ± 0.05 a	-0.48 ± 0.03 a	-0.52 ± 0.05 a	-0.31 ± 0.04 a
CHI*IR	-0.17 ± 0.03 a	-0.17 ± 0.02 a	-0.30 ± 0.04 a	-0.44 ± 0.04 b	-0.55 ± 0.05 a	-0.44 ± 0.03 a	-0.52 ± 0.05 a	-0.28 ± 0.04 a
CHI*NI	-0.24 ± 0.03 a	-0.19 ± 0.02 a	-0.31 ± 0.04 a	-0.46 ± 0.04 b	-0.58 ± 0.05 a	-0.44 ± 0.03 a	-0.54 ± 0.05 a	-0.32 ± 0.04 a
CON*IR	-0.17 ± 0.03 a	-0.16 ± 0.02 a	-0.26 ± 0.04 a	-0.28 ± 0.04 a	-0.50 ± 0.05 a	-0.42 ± 0.04 a	-0.49 ± 0.05 a	-0.20 ± 0.04 a
CON*NI	-0.17 ± 0.03 a	-0.16 ± 0.02 a	-0.28 ± 0.04 a	-0.44 ± 0.04 ab	-0.55 ± 0.05 a	-0.42 ± 0.04 a	-0.59 ± 0.05 a	-0.28 ± 0.04 a
Significance								
Cover Crop	0.5054	0.3317	0.4231	0.0564	0.4840	0.5770	0.9867	0.2243
Irrigation	0.1302	0.4011	0.7812	0.2860	0.8097	0.6896	0.5439	0.2959
CC X IR	0.1169	0.9559	0.4689	**0.0166**	0.5086	0.7611	0.5414	0.4230

Treatment abbreviations: BW: Buckwheat; CHI: Chicory; CON: Glyphosate sprayed control; IR: Irrigated; NI: Not irrigated. Within year columns, treatment means that are followed by the same letter are not significantly different at $P \leq 0.05$ level using Tukey HSD test

Table 3.4. Nutrient analysis of petioles collected at veraison from Riesling grapevines with different under-vine treatments.

Treatment	N (ppm)		P (ppm)		K (ppm)		Ca (ppm)		Mg (ppm)	
Cover Crop	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013
BW	6000 ±200 b	6300 ±200 b	2091 ±192 a	3872.0 ±314 a	28317 ±1753 a	36817 ±2564a	24889 ±1024 a	18261 ±625 a	7945 ±372 a	5655 ±451 a
CHI	6300 ±200 ab	6300 ±200 b	2141 ±200 a	4388.4 ±314 a	32382 ±1868 a	40930 ±2564a	24974 ±1030 a	20094 ±625 a	7223 ±391 a	5310 ±451 a
CON	6500 ±200 b	7300 ±200 a	2042 ±191 a	4471.6 ±314 a	31313 ±1748 a	35475 ±2564a	25919 ± 1016 a	19360 ±625 a	7702 ±372 a	5219 ±451 a
Irrigation										
IR	6300 ±200 b	6800 ±200 a	2036 ±223 a	4582.5 ±232 a	32436 ±1921 a	38615 ±2093a	25511 ± 910 a	18391 ±510 a	7441 ±435 a	5379 ±368 a
NI	6300 ±200 b	6500 ±200 a	2147 ±219 a	3972.2 ±232 a	28905 ±1861 a	36867 ±2093a	25010 ± 906 a	19547 ±510 a	7805 ±425 a	5411 ±368 a
CC*IR										
BW*IR	6000 ±200 bc	6400 ±300 a	1983 ±265 a	4172.3 ±403 a	30316 ±2483 a	36284 ±3626a	25079 ± 1086 a	18016 ±884 a	7936 ±528 a	5538 ±638 a
BW*NI	5900 ±200 c	6200 ±300 a	2198 ±263 a	3771.7 ±403 a	26319 ±475 a	37350 ±3626a	24697 ± 1085 a	18505 ±884 a	7954 ±526 a	5771 ±638 a
CHI*IR	6100 ±200 bc	6500 ±300 a	2143 ±288 a	5063.9 ±403 a	34040 ±2798 a	40511 ±3626a	24939 ± 1109 a	19802 ±884 a	7083 ±580 a	5464 ±638 a
CHI*NI	6500 ±200 ab	6200 ±300 a	2139 ±263 a	3713.0 ±403 a	30725 ±2475 a	41349 ±3626a	25010 ± 1085 a	20387 ±884 a	7364 ±526 a	5155 ±638 a
CON*IR	6700 ±200 a	7600 ±300 a	1980 ±263 a	4511.6 ±403 a	32954 ±2483 a	39048 ±3626a	26515 ± 1080 a	18974 ±884 a	7306 ±528 a	5133 ±638 a
CON*NI	6300 ±200 abc	7000 ±300 a	2103 ±263 a	4431.8 ±403 a	29671 ±2462 a	31902 ±3626a	25322 ± 1076 a	19747 ±884 a	8098 ±523 a	5306 ±638 a
P-value										
Cover Crop	**0.0299**	0.0082	0.8718	0.5092	0.1638	0.316	0.6213	0.1422	0.2115	0.7745
Irrigation	0.9328	0.1830	0.7305	0.0665	0.2181	0.562	0.4897	0.4051	0.5634	0.9517
CC X IR	0.0192	0.8228	0.8285	0.2358	0.9804	0.451	0.2006	0.9868	0.6287	0.8977

Treatment	Fe (ppm)		Mn (ppm)		B (ppm)		Zn (ppm)		Cu (ppm)	
Cover Crop	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013
BW	23.33 ± 2.27 a	38.58 ±5.1 a	159.57 ±37 a	204.15 ±98 a	36.47 ±0.9 a	36.22 ±1.2 a	64.47 ± 3.59 a	46.12 ±2.36 a	7.08 ± 0.45 a	12.58 ±0.78 a
CHI	22.55 ± 2.45 a	32.87 ±5.5 a	152.61 ±37 a	133.07 ±98 a	40.19 ±0.9 a	37.4 ±1.2 a	64.08 ± 3.81 a	47.36 ±2.36 a	7.33 ± 0.47 a	12.08 ±0.78 a
CON	27.16 ± 2.27 a	33.68 ±5.1 a	161.8 ±37 a	227.53 ±98 a	39.78 ±0.9 a	35.5 ±1.2 a	65.97 ± 3.61	46.93 ±2.36 a	7.62 ± 0.45 a	11.62 ±0.78 a
Irrigation										
IR	24.78 ± 1.95 a	36.02 ±4.1 a	147.42 ±27 a	157.40 ±80 a	40.12 ±0.8 a	36.48 ±1.0 a	63.93 ± 2.59 a	1.91 ±1.91 a	7.52 ± 0.32 a	12.36 ±0.62 a
NI	23.92 ± 1.85 a	34.06 ±4.0 a	168.58 ±27 a	219.10 ±98 a	39.51 ±0.8 a	36.33 ±1.0 a	65.75 ± 2.43 a	47.12 ±1.91 a	7.17 ± 0.30 a	11.84 ±0.62 a
CC*IR										
BW*IR	21.21 ± 3.21 a	40.17 ±6.7 a	149.34 ±37 a	260.23 ±138 a	40.10 ±1.1 a	35.69 ±1.7 a	65.39 ± 4.21	44.74 ±3.31 a	7.42 ± 0.52 a	12.55 ±1.03 a
BW*NI	25.47 ± 3.21 a	36.98 ±6.7 a	169.80 ±37 a	148.07 ±138 a	38.85 ±1.1 a	36.75 ±1.7 a	63.54 ± 4.21	46.51 ±3.31 a	6.75 ± 0.52 a	12.61 ±1.03 a
CHI*IR	26.14 ± 3.70 a	32.56 ±7.8 a	162.43 ±37 a	128.64 ±138 a	40.90 ±1.1 a	37.38 ±1.7 a	65.18 ± 4.91	49.03 ±3.31 a	7.02 ± 0.52 a	11.97 ±1.03 a
CHI*NI	18.96 ± 3.21 a	33.17 ±6.7 a	142.79 ±37 a	137.50 ±138 a	39.49 ±1.1 a	37.53 ±1.7 a	62.98 ± 4.21	45.66 ±3.31 a	7.64 ± 0.52 a	12.20 ±1.03 a
CON*IR	26.99 ± 3.21 a	35.33 ±6.7 a	130.48 ±37 a	83.33 ±138 a	39.36 ±1.1 a	36.37 ±1.7 a	61.20 ± 4.22	45.67 ±3.31 a	8.10 ± 0.52 a	12.55 ±1.03 a
CON*NI	27.34 ± 3.21 a	32.02 ±6.7 a	193.14 ±37 a	371.73 ±138 a	40.19 ±1.1 a	34.72 ±1.7 a	70.72 ± 4.23	48.20 ±3.31 a	7.13 ± 0.52 a	10.70 ±1.03 a
P-value										
Cover Crop	0.3451	0.6188	0.9759	0.7782	0.7507	0.533	0.9319	0.9332	0.7132	0.6764
Irrigation	0.7537	0.7156	0.1141	0.5906	0.4063	0.917	0.5137	0.8160	0.3118	0.5168
CC X IR	0.2523	0.9457	0.0782	0.3515	0.3670	0.724	0.1746	0.5895	0.1736	0.4979

Treatment abbreviations: BW: Buckwheat; CHI: Chicory; CON: Glyphosate sprayed control; IR: Irrigated; NI: Not irrigated. Values are an average of four samples of 100 petioles collected from each experimental unit ± SE for all measures. Within year columns, treatment means that are followed by the same letter are not significantly different at $P \leq 0.05$ level using Tukey HSD test

Vine Water Potential

To evaluate the soil moisture in the rooting zone, predawn leaf water potential was quantified for two dates in 2012 and 2013. Under-vine treatments did not affect predawn leaf water potential (Table 3.3). In both 2012 and 2013, predawn water potential values never exceeded -0.35 MPa or -0.24 MPa respectively.

Under-vine cover crop treatments did not impact midday stem water potential of vines (Table 3.3), but there was a significant interaction effect between cover crop and irrigation for one date in each season. On 29 July 2012, BW*IR had a greater water potential (-0.62 MPa) compared to CHI*IRR (-0.72 MPa). On 13 July 2013, CON*IR had a greater midday stem water potential (-0.28 MPa) compared to BW*IR, CHI*IR, and CHI*NI treatments.

Petiole tissue nutrient analysis

Petioles were analyzed for nutrient concentrations from each experimental unit for 2012 and 2013 (Table 3.4). In both years, under-vine cover crops were found to reduce nitrogen content in petioles. BW significantly reduced nitrogen compared to CON by 500 ppm in 2012 and BW and CHI treatments were 1000ppm less than the CON nitrogen value in 2013. There were no significant differences among under-vine treatments for P, K, Ca, Mg, Mn, B, Zn, or Cu concentrations.

Table 3.5. Yield component and juice characteristic measures of Riesling grapevines in the Finger Lakes, NY from 2011 to 2013.

Treatments	**Clusters per Vine**		**Yield per Vine (kg)**		**Weight per Cluster (g)**	
Cover Crop	2012	2013	2012	2013	2012	2013
BW	64.64 ± 3.78 a	99.21 ± 3.51 a	4.49 ± 0.27 a	7.46 ± 0.34 a	70.34 ± 4.06 a	73.66 ± 2.60 a
CHI	70.96 ± 3.78 a	94.11 ± 3.47 a	5.26 ± 0.27 a	5.52 ± 0.34 b	74.21 ± 4.06 a	57.49 ± 2.57 b
CON	65.56 ± 3.75 a	101.48 ± 3.43 a	4.57 ± 0.26 a	7.57 ± 0.33 a	70.56 ± 4.03 a	76.54 ± 2.56 a
Irrigation						
IR	66.21 ± 2.66 a	99.43 ± 2.93 a	4.84 ± 0.26 a	7.04 ± 0.25 a	73.76 ± 3.57 a	70.68 ± 2.58 a
NI	67.90 ± 2.62 a	97.10 2.87 a	4.70 ± 0.25 a	6.67 ± 0.25 a	69.65 ± 3.54 a	67.77 ± 2.54 a
CC*I						
BW*IR	61.33 ± 4.64 a	105.03 ± 4.54 a	4.34 ± 0.38 a	7.90 ± 0.44 a	71.61 ± 5.68 a	74.48 ± 3.65 a
BW*NI	67.94 ± 4.54 a	93.39 ± 4.31 a	4.65 ± 0.37 a	7.03 ± 0.43 a	69.06 ± 5.60 a	72.83 ± 3.51 a
CHI*IR	72.47 ± 4.64	94.78 ± 4.42 a	5.37 ± 0.38 a	5.60 ± 0.44 a	75.12 ± 5.68 a	57.67 ± 3.58 a
CHI*NI	69.43 ± 4.54 a	93.44 ± 4.31 a	5.14 ± 0.37 a	5.45 ± 0.43 a	73.31 ± 5.60 a	57.30 ± 3.51 a
CON*IR	64.81 ± 4.54	98.48 ± 4.31 a	4.81 ± 0.37 a	7.62 ± 0.43 a	74.54 ± 5.60 a	79.90 ± 3.52 a
CON*NI	66.31 ± 4.54	104.48 ± 3.32 a	4.32 ± 0.37 a	7.53 ± 0.42 a	66.57 ± 5.60 a	73.17 ± 3.52
Significance						
Cover Crop	0.4730	0.2022	0.0431	0.0030	0.7297	0.0020
Irrigation	0.5739	0.4510	0.7163	0.2631	0.4347	0.4478
CC X IR	0.4282	0.0694	0.4758	0.5498	0.8217	0.5351

	Berry Weight (g)		**Berries per Cluster**		**Soluble Solids (°Brix)**	
Cover Crop	2012	2013	2012	2013	2012	2013
BW	1.48 ± 0.06 a	1.60 ± 0.39 a	47.63 ± 2.11 a	44.63 ± 1.36 a	17.32 ± 0.54 a	14.11 ± 0.40 a
CHI	1.44 ± 0.06 a	1.42 ± 0.39 b	48.10 ± 2.11 a	39.08 ± 1.36 b	16.28 ± 0.54 a	14.36 ± 0.42 a
CON	1.50 ± 0.06 a	1.66 ± 0.39 a	47.91 ± 2.10 a	45.34 ± 1.35 a	17.59 ± 0.54 a	14.58 0.40 a
Irrigation						
IR	1.52 ± 0.05 a	1.54 ± 0.03 a	47.77 ± 2.24 a	44.97 ± 1.52 a	17.29 ± 0.41 a	14.67 ± 0.31 a
NI	1.44 ± 0.05 a	1.58 ± 0.03 a	48.00 ± 2.24 a	41.07 ± 1.52 a	16.84 ± 0.41 a	14.03 ± 0.31 b
Cover Crop x Irrigation						
BW*IR	1.51 ± 0.08 a	1.56 ± 0.05 a	48.38 ± 2.59 a	48.79 ± 1.92 a	17.56 ± 0.66 a	14.18 ± 0.45 a
BW*NI	1.45 ± 0.08 a	1.64 ± 0.05 a	46.88 ± 2.59 a	40.47 ± 1.92 a	17.08 ± 0.66 a	14.05 ± 0.45 a
CHI*IR	1.49 ± 0.08 a	1.42 ± 0.05 a	48.26 ± 2.59 a	40.63 ± 1.92 a	16.53 ± 0.66 a	15.10 ± 0.45 a
CHI*NI	1.46 ± 0.08 a	1.41 ± 0.05 a	47.94 ± 2.59 a	37.54 ± 1.92 a	16.04 ± 0.66 a	13.61 ± 0.51 a
CON*IR	1.58 ± 0.08 a	1.64 ± 0.05 a	46.66 ± 2.57 a	45.48 ± 1.91 a	17.78 ± 0.66 a	14.73 ± 0.45 a
CON*NI	1.43 ± 0.08 a	1.67 ± 0.05 a	49.17 ± 2.57 a	45.20 ± 1.91 a	17.40 ± 0.66 a	14.43 ± 0.45 a
Significance						
Cover Crop	0.9273	0.0077	0.9593	0.0062	0.2341	0.6777
Irrigation	0.1587	0.3558	0.9327	0.1579	0.3875	0.0351
CC X IR	0.6479	0.2415	0.3996	0.0719	0.9931	0.1337

	Titratable Acidity (g/L)		**pH**		**Yeast Assimilable Nitrogen (ppm)**	
Cover Crop	2012	2013	2012	2013	2012	2013
BW	8.30 ± 0.24 ab	7.20 ± 0.21 a	3.27 ± 0.04 a	3.21 ± 0.02 a	55.74 ± 7.82 a	104.77 ± 10.5 ab
CHI	7.67 ± 0.24 b	6.64 ± 0. 21 a	3.22 ± 0.04 a	3.25 ± 0.02 a	45.86 ± 7.82 a	82.85 ± 9.9 b
CON	8.68 ± 0.24 a	7.44 ± 0.21 a	3.26 ± 0.04 a	3.22 ± 0.02 a	68.36 ± 7.74 a	117.73 ± 9.8 a
Irrigation						
IR	8.46 ± 0.24 a	7.17 ± 0.18 a	3.21 ± 0.04 b	3.22 ± 0,02 a	55.79 ± 6.98 a	103.70 ± 8.7 a
NI	7.97 ± 0.24 a	7.02 ± 0.18 a	3.29 ± 0.04 a	3.23 ± 0.02 a	57.52 ± 6.98 a	99.87 ± 8.4 a
Cover Crop x Irrigation						
BW*IR	8.47 ± 0.32 a	7.22 ± 0.25 a	3.23 ± 0.05 a	3.21 ± 0.03 a	57.15 ± 9.27 a	94.93 ± 14.31 ab
BW*NI	8.13 ± 0.32 a	7.18 ± 0.25 a	3.30 ± 0.05 a	3.21 ± 0.03 a	54.34 ± 9.27 a	114.60 ± 12.32 ab
CHI*IR	7.71 ± 0.32 a	6.81 ± 0.25 a	3.17 ± 0.05 a	3.24 ± 0.03 a	35.16 ± 9.27 a	78.59 ± 12.36 b
CHI*NI	7.62 ± 0.32 a	6.47 ± 0.25 a	3.27 ± 0.05 a	3.26 ± 0.03 a	56.56 ± 9.27 a	87.12 ± 12.31 ab
CON*IR	9.19 ± 0.32 a	7.48 ± 0.25 a	3.22 ± 0.05 a	3.22 ± 0.03 a	75.07 ± 9.19 a	137.59 ± 12.32 a
CON*NI	8.16 ± 0.32 a	7.39 ± 0.25 a	3.31 ± 0.05 a	3.23 ± 0.03 a	61.66 ± 9.19 a	97.87 ± 12.31 ab
Significance						
Cover Crop	0.0337	0.0517	0.3588	0.2936	0.1673	0.0328
Irrigation	0.1774	0.4183	0.0569	0.7827	0.8147	0.6834
CC X IR	0.2094	0.7082	0.8979	0.9499	0.0730	0.0456

Treatment abbreviations: BW: Buckwheat; CHI: Chicory; CON: Glyphosate sprayed control; IR: Irrigated; NI: Not irrigated. Within year columns, treatment means that are followed by the same letter are not significantly different at $P \le 0.05$ level using Tukey HSD test

Yield Components and Juice Characteristics

In 2012, yield components were not impacted by treatments (Table 3.5). In the second year of establishment, while the number of clusters per vine was not affected, CHI reduced the yield per vine and weight per cluster by 21% and individual berry weight and berries per cluster by 11% in 2013 compared to CON.

Soluble solids of juice ranged from 16.28-17.78° Brix in 2012 and 13.61 – 15.10° Brix in 2013 and under-vine treatments did not impact soluble solids or pH of juice at harvest. Titratable acidity was reduced by 1.01 g/L for CHI treatments compared to CON in 2012, while the reduced acidity in CHI treatments in 2013 was not statistically significant (p=0.0517). YAN was not impacted by treatment in 2012, but there was a significant cover crop effect and a significant interaction between the cover crop and irrigation, with CHI*IR treatments showing a significantly reduced YAN value by 59.0 ppm compared to the CON*IR treatment.

Vegetative Growth

Treatments did not impact measures of vegetative growth in 2012 (Table 3.6). In 2013 however, CHI reduced pruning weights by 0.32 to 0.40 kg compared to CON and BW respectively and reduced the average cane diameter 0.86 mm compare to CON.

Under-vine treatments did not impact EQPA parameters in 2012, but were found to have an effect in 2013 (Table 3.7). In 2013, CHI was found to decrease the leaf layer number by 0.49 layers, occlusion layer number by 0.72 layers, had 12.5% fewer interior clusters, and increased the cluster and leaf exposure flux availabilities by 10% and 5% respectively. Shoot lengths were reduced by 34.1 cm for the CHI treatment compared to

CON on 18 Jul 2013, but otherwise there were no significant differences among under-vine treatments for shoot length and shoot growth rate in either year (Table 3.8).

Table 3.6. Vegetative growth measures of Riesling grapevines in the Finger Lakes, NY from 2011 to 2013. Under-vine cover crop and herbicide control treatments were established at the beginning of the growing season of each year. Vines were dormant pruned in winter. Shoot diameters and shoot tip activity measures were taken at 50% berry veriason.

	Pruning Weight		**Ravaz Index (kg/kg)**		**Shoot Diameters (mm)**		**Active Shoot Tips (%)**
Cover Crop	**2012**	**2013**	**2012**	**2013**	**2012**	**2013**	**2012**
BW	0.77 ± 0.09 a	1.24 ± 0.06 a	6.18 ± 0.69 a	6.28 ± 0.72 a	6.62 ± 0.36 a	6.51 ± 0.21 ab	20.3 ± 2.9 a
CHI	0.78± 0.09 a	0.84 ± 0.06 b	7.84 ± 0.69 a	7.49 ± 0.72 a	6.68 ± 0.36 a	6.19 ± 0.21 b	24.6 ± 2.9 a
CON	0.82 ± 0.09 a	1.16 ± 0.06 a	6.34 ± 0.68 a	7.20 ± 0.71 a	6.53 ± 0.37 a	7.05 ± 0.21 a	27.6 ± 2.9 a
Irrigation							
IR	0.86 ± 0.09 a	1.13 ± 0.05 a	6.38 ± 0.54 a	6.94 ± 0.54 a	6.62 ± 0.31 a	6.51± 0.17 a	26.4 ± 2.9 a
NI	0.72 ± 0.09 a	1.03 ± 0.05 a	7.19 ± 0.54 a	7.04 ± 0.53 a	6.59 ± 0.31 a	6.66 ± 0.17 a	21.9 ± 2.9 a
CC X IR							
BW*IR	0.78 ± 0.11 a	1.27 ± 0.09 a	5.75 ± 0.86 a	6.36 ± 0.88 a	6.56 ± 0.41 a	6.26 ± 0.30 a	26.0 ± 4 a
BW*NI	0.75 ± 0.11 a	1.22 ± 0.08 a	6.60 ± 0.85 a	6.20 ± 0.84 a	6.68 ± 0.41 a	6.76 ± 0.30 a	14.6 ± 4 a
CHI*IR	0.78 ± 0.11 a	0.85 ± 0.08 a	7.88 ± 0.86 a	7.69 ± 0.86 a	6.66 ± 0.41 a	6.16 ± 0.30 a	22.9 ± 4 a
CHI*NI	0.78 ± 0.11 a	0.83 ± 0.08 a	7.79 ± 0.86 a	7.29 ± 0.86 a	6.69 ± 0.41 a	6.22 ± 0.30 a	26.3 ± 4 a
CON*IR	1.01 ± 0.11 a	1.28 ± 0.08 a	5.51 ± 0.85 a	6.77 ± 0.85 a	6.67 ± 0.41 a	7.12 ± 0.30 a	30.4 ± 4 a
CON*NI	0.63 ± 0.11 a	1.03 ± 0.08 a	7.17 ± 0.85 a	7.63 ± 0.84 a	6.39 ± 0.41 a	6.99 ± 0.30 a	24.7 ± 4 a
Significance							
Cover Crop	0.8277	<0.0001	0.2115	0.4367	0.9355	0.0316	0.1949
Irrigation	0.1621	0.1228	0.2321	0.8566	0.8751	0.5642	0.2836
CC X IR	0.0882	0.3249	0.5093	0.5983	0.7882	0.5706	0.1275

Treatment abbreviations: BW: Buckwheat; CHI: Chicory; CON: Glyphosate sprayed control; IR: Irrigated; NI: Not irrigated. Within year columns, treatment means that are followed by the same letter are not significantly different at $P \leq 0.05$ level using Tukey HSD test

Table 3.7. Enhanced Point Quadrant Analysis (EPQA) characteristics of Riesling grapevines with different under-vine treatments for 2012-2013 measured at veraison.

	Leaf Layer #		**% Interior Leaves**		**% Interior Clusters**		**Occlusion Layer #**	
Treatment	2012	2013	2012	2013	2012	2013	2012	2013
Cover Crop								
BW	2.74 ±0.10 a	3.30 ±0.13 ab	36.99 ±1.90 a	45.35 ±1.97 a	80.38 ±2.14 a	84.09 ±2.56 a	3.82 ±0.17 a	4.50 ±0.18 ab
CHI	2.78 ±0.10 a	2.98 ±0.13 b	37.30 ±1.90 a	43.39 ±1.97 a	79.21 ±2.14 a	74.33 ±2.56 b	3.85 ±0.17 a	4.14 ±0.18 b
CON	2.93 ±0.10 a	3.47 ±0.13 a	40.11 ±1.91 a	47.52 ±1.97 a	81.63 ±2.14 a	86.84 ±2.56 a	3.95 ±0.17 a	4.86 ±0.18 a
Irrigation								
IR	2.75 ±0.09 a	3.32 ±0.13 a	37.93 ±1.38 a	45.51 ±1.72 a	79.73 ±1.75 a	83.69 ±2.15 a	3.81 ±0.16 a	4.51 ±0.16 a
NI	2.89 ±0.09 a	3.17 ±0.13 a	38.38 ±1.38 a	45.33 ±1.72 a	81.08 ±1.75 a	79.81 ±2.15 a	3.93 ±0.16 a	4.49 ±0.16 a
CC X IR								
BW*IR	2.57 ±0.13 a	3.38 ±0.16 a	35.79 ±2.30 a	45.29 ±2.34 a	79.47 ±3.03 a	84.89 ±3.53 a	3.95 ±0.16 a	4.36 ±0.20 a
BW*NI	2.91 ±0.13 a	3.21 ±0.16 a	38.20 ±2.30 a	45.42 ±2.34 a	81.30 ±3.03 a	83.27 ±3.53 a	3.57 ±0.17 a	4.63 ±0.20 a
CHI*IR	2.76 ±0.13 a	2.97 ±0.16 a	37.46 ±2.30 a	42.81 ±2.34 a	79.27 ±3.03 a	75.42 ±3.53 a	3.99 ±0.17 a	4.13 ±0.20 a
CHI*NI	2.80 ±0.13 a	2.99 ±0.16 a	37.15 ±2.30 a	43.95 ±2.34 a	79.14 ±3.03 a	73.25 ±3.53 a	3.81 ±0.17 a	4.15 ±0.20 a
CON*IR	2.91 ±0.13 a	3.61 ±0.16 a	40.55 ±2.30 a	48.42 ±2.33 a	80.47 ±3.03 a	90.76 ±3.54 a	4.05 ±0.17 a	5.04 ±0.20 a
CON*NI	2.95 ±0.13 a	3.32 ±0.16 a	39.67 ±2.30 a	46.61 ±2.33 a	82.80 ±3.03 a	82.92 ±3.54 a	3.87 ±0.17 a	4.69 ±0.20 a
Significance								
Cover Crop	0.4297	0.0125	0.4708	0.1883	0.7297	0.0084	0.8070	0.0195
Irrigation	0.2930	0.2979	0.8031	0.9040	0.5936	0.2471	0.5020	0.8528
CC X IR	0.3481	0.4882	0.6246	0.7131	0.9137	0.6308	0.3925	0.0864

	Cluster Exposure Layer		**Leaf Exposure Layer**		**Cluster Exposure Flux Availability**		**Leaf Exposure Flux Availability**	
Treatment	2012	2013	2012	2013	2012	2013	2012	2013
Cover Crop								
BW	1.07 ±0.05 a	1.25 ±0.09 a	0.46 ±0.03 a	0.55 ±0.04 a	0.16 ±0.03 a	0.14 ±0.01 b	0.34 ±0.06 a	0.32 ±0.01 ab
CHI	1.02 ±0.05 a	1.02 ±0.09 a	0.45 ±0.03 a	0.52 ±0.04 a	0.19 ±0.03 a	0.21 ±0.01 a	0.29 ±0.06 a	0.34 ±0.01 a
CON	1.09 ±0.05 a	1.33 ±0.09 a	0.49 ±0.03 a	0.61 ±0.04 a	0.14 ±0.03 a	0.11 ±0.01 b	0.33 ±0.06 a	0.29 ±0.01 b
Irrigation								
IR	1.06 ±0.05 a	1.25 ±0.07 a	0.47 ±0.02 a	0.56 ±0.04 a	0.16 ±0.02 a	0.13 ±0.01 b	0.31 ±0.05 a	0.31 ±0.01 a
NI	1.06 ±0.05 a	1.14 ±0.07 a	0.57 ±0.02 a	0.56 ±0.04 a	0.17 ±0.02 a	0.17 ±0.01 a	0.33 ±0.05 a	0.32 ±0.01 a
CC X IR								
BW*IR	1.04 ±0.06 a	1.25 ±0.11 a	0.45 ±0.04 a	0.54 ±0.04 a	0.19 ±0.04 a	0.14 ±0.02 c	0.30 ±0.06 a	0.31 ±0.02 a
BW*NI	1.09 ±0.06 a	1.25 ±0.11 a	0.47 ±0.04 a	0.56 ±0.04 a	0.14 ±0.04 a	0.14 ±0.02 bc	0.38 ±0.06 a	0.32 ±0.02 a
CHI*IR	1.03 ±0.06 a	1.05 ±0.11 a	0.46 ±0.04 a	0.49 ±0.04 a	0.16 ±0.04 a	0.20 ±0.02 ab	0.30 ±0.06 a	0.34 ±0.02 a
CHI*NI	1.01 ±0.06 a	0.99 ±0.11 a	0.45 ±0.04 a	0.54 ±0.04 a	0.21 ±0.04 a	0.21 ±0.02 a	0.28 ±0.06 a	0.34 ±0.02 a
CON*IR	1.10 ±0.06 a	1.47 ±0.11 a	0.49 ±0.04 a	0.64 ±0.04 a	0.12 ±0.04 a	0.05 ±0.02 d	0.34 ±0.06 a	0.26 ±0.02 a
CON*NI	1.09 ±0.06 a	1.19 ±0.11 a	0.49 ±0.04 a	0.58 ±0.04 a	0.16 ±0.04 a	0.16 ±0.02 abc	0.32 ±0.06 a	0.31 ±0.02 a
Significance								
Cover Crop	0.3459	0.0619	0.6542	0.0660	0.4368	<0.0001	0.6023	0.0231
Irrigation	0.8748	0.1834	0.8660	0.9886	0.7702	0.0021	0.6904	0.1812
CC X IR	0.7636	0.3477	0.8079	0.2976	0.3463	0.0034	0.5088	0.1916

Treatment abbreviations: BW: Buckwheat; CHI: Chicory; CON: Glyphosate sprayed control; IR: Irrigated; NI: Not irrigated. Within year columns, treatment means that are followed by the same letter are not significantly different at $P \leq 0.05$ level using Tukey HSD test

Table 3.8. Shoot lengths and growth rates of Riesling grapevines in the Finger Lakes, NY from 2012 to 2013.

2012

Treatment	Shoot Length (cm) 13 Jun	Shoot Length (cm) 1 Jul	Shoot Length (cm) 14 Jul	Shoot Growth Rate (cm/day) 13 Jun –1 Jul	Shoot Growth Rate (cm/day) 1 Jul – 14 Jul
Cover Crop					
BW	57.3 ± 5.0	74.6 ± 6.4	77.1 ± 11.6	1.0 ± 0.2	0.1 ± 0.1
CHI	61.4 ± 5.0	85.4 ± 6.4	94.6 ± 11.6	1.4 ± 0.2	0.2 ± 0.1
CON	53.8 ± 5.0	73.00 ± 7.8	74.7 ± 11.6	1.1 ± 0.2	0.3 ± 0.1
Irrigation					
IR	57.8 ± 5.0	78.4 ± 5.7	82.7 ± 9.5	1.2 ± 0.1	0.2 ± 0.1
NI	57.3 ± 5.0	76.9 ± 5.7	81.6 ± 9.5	1.2 ± 0.1	0.2 ± 0.1
CC x Irrigation					
BW*IR	57.7 ± 5.0	73.7 ± 7.8	78.0 ± 16.3	0.9 ± 0.2	0.2 ± 0.1
BW*NI	56.8 ± 5.0	75.5 ± 7.8	76.2 ± 16.3	1.1 ± 0.2	0.1 ± 0.1
CHI*IR	59.7 ± 5.0	84.6 ± 7.8	84.5 ± 16.3	1.4 ± 0.2	0.1 ± 0.1
CHI*NI	63.3 ± 5.0	86.2 ± 7.8	104.8 ± 16.3	1.3 ± 0.2	0.3 ± 0.1
CON*IR	55.9 ± 5.0	76.8 ± 7.8	85.5 ± 16.3	1.3 ± 0.2	0.5 ± 0.1
CON*NI	51.7 ± 5.0	69.2 ± 7.8	63.9 ± 16.3	1.0 ± 0.2	0.2 ± 0.1
Significance					
Cover Crop	0.8837	0.7989	0.9404	0.1328	0.3397
Irrigation	0.6173	0.7042	0.4514	0.5866	0.6174
CC X IR	0.2539	0.1181	0.4260	0.6052	0.2101

2013

Treatment	Shoot Length (cm) 4 Jun	Shoot Length (cm) 24 Jun	Shoot Length (cm) 10 Jul	Shoot Length (cm) 18 Jul	Shoot Length (cm) 5 Aug	Shoot Growth Rate (cm/day) 4 Jun – 24 Jun	Shoot Growth Rate (cm/day) 24 Jun – 10 Jul	Shoot Growth Rate (cm/day) 10 Jul – 18 Jul	Shoot Growth Rate (cm/day) 18 Jul – 5 Aug
Cover Crop									
BW	41.3 ± 2.0	77.0 ± 4.9	100.6 ± 8.6	113.4 ± 10.5 ab	145.7 ± 23.6	1.8 ± 0.2	1.5 ± 0.3	1.6 ± 0.5	0.4 ± 1.0
CHI	38.2 ± 2.0	67.5 ± 4.9	89.4 ± 8.5	93.4 ± 10.4 b	100.7 ± 22.8	1.5 ± 0.2	1.4 ± 0.3	0.7 ± 0.5	0.2 ± 1.0
CON	44.3 ± 2.0	80.6 ± 4.9	109.8 ± 8.6	127.5 ± 10.6 a	119.6 ± 23.7	1.8 ± 0.2	1.8 ± 0.3	2.0 ± 0.5	0.5 ± 1.0
Irrigation									
IR	42.6 ± 1.7	78.9 ± 3.9	106.0 ± 7.0	117.0 ± 8.5	117.1 ± 19.8	1.8 ± 0.1	1.7 ± 0.2	1.6 ± 0.3	0.4 ± 0.8
NI	39.9 ± 1.7	71.1 ± 4.0	93.8 ± 7.0	105.9 ± 8.7	126.9 ± 19.9	1.6 ± 0.1	1.4 ± 0.2	1.1 ± 0.4	0.4 ± 0.8
CC x Irrigation									
BW*IR	42.2 ± 2.8	78.7 ± 6.4	100.8 ± 11.3	114.1 ± 13.8	123.3 ± 31.0	1.8 ± 0.2	1.4 ± 0.3	1.7 ± 0.6	0.6 ± 1.4
BW*NI	40.3 ± 2.8	75.2 ± 6.4	100.4 ± 11.1	112.7 ± 13.4	168.1 ± 30.7	1.8 ± 0.2	1.6 ± 0.3	1.4 ± 0.6	0.3 ± 1.4
CHI*IR	38.1 ± 2.8	68.9 ± 6.4	92.0 ± 11.1	95.0 ± 3.4	97.1 ± 29.9	1.5 ± 0.2	1.4 ± 0.3	0.8 ± 0.6	0.1 ± 1.3
CHI*NI	38.2 ± 2.8	66.1 ± 6.4	86.8 ± 11.2	91.8 ± 13.4	104.2 ± 29.7	1.4 ± 0.2	1.3 ± 0.3	0.6 ± 0.6	0.3 ± 1.3
CON*IR	47.3 ± 2.8	89.2 ± 6.4	125.1 ± 11.2	141.9 ± 13.4	130.8 ± 31.0	2.1 ± 0.2	2.2 ± 0.3	2.2 ± 0.6	0.5 ± 1.4
CON*NI	41.2 ± 2.8	71.9 ± 6.4	94.4 ± 11.3	113.0 ± 14.2	108.3 ± 31.5	1.6 ± 0.2	1.4 ± 0.3	1.9 ± 0.6	0.5 ± 1.8
Significance									
Cover Crop	0.0982	0.1245	0.2067	**0.0480**	0.2691	0.2119	0.4902	0.2502	0.2579
Irrigation	0.3027	0.112	0.1484	0.2669	0.6907	0.1310	0.3647	0.5256	0.6652
CC X IR	0.5293	0.3990	0.2861	0.4645	0.4949	0.4170	0.2617	0.990	0.3171

Treatment abbreviations: BW: Buckwheat; CHI: Chicory; CON; glyphosate sprayed control; IR: Irrigated; NI: not irrigated. Analysis of variance was conducted using a mixed model in JMP. Within year columns, treatment means that are followed by the same letter are not significantly different at $P \leq 0.05$ level using Tukey HSD test.

Winemaking and Multi-Dimensional Sorting Analysis of Wine Aroma

For each replicate, wine was analyzed at bottling (Table 3.9). In both years, wine replicates from BW and CHI treatments had lower malic acid than CON.

Table 3.9. Properties of Riesling wine for two five-gallon replicates for each experimental treatment for 2012 and 2013.

Treatment	TA (g/L)	pH	Organic Acids (g/L)				
2012			**Citric**	**Tartaric**	**Malic**	**Lactic**	**Acetic**
BW, IR (1)	7.5	3.10	0.25	3.3	2.5	0.2	0.10
BW, IR (2)	7.4	3.07	0.25	3.3	2.5	0.2	0.11
BW, NI (1)	7.3	3.02	0.22	3.5	2.2	0.3	0.09
BW, NI (2)	7.3	3.02	0.22	3.5	2.2	0.2	0.07
CHI, IR (1)	7.4	3.00	0.21	3.4	2.3	0.2	0.08
CHI, IR (2)	7.4	3.00	0.22	3.5	2.2	0.2	0.08
CHI, NI (1)	7.2	3.02	0.21	3.5	2.0	0.3	0.10
CHI, NI (2)	7.3	3.01	0.21	3.5	2.0	0.2	0.08
CON, IR (1)	7.6	2.94	0.19	3.9	2.0	0.3	0.10
CON, IR (2)	7.5	2.93	0.18	3.8	2.0	0.2	0.10
CON, NI (1)	7.4	2.98	0.20	3.6	2.1	0.3	0.10
CON, NI (2)	7.3	2.99	0.19	3.6	2.1	0.2	0.10
2013							
BW, IR (1)	7.5	3.18	0.31	2.9	2.7	0.3	0.20
BW, IR (2)	7.6	3.16	0.28	2.9	2.7	0.4	0.19
BW, NI (1)	7.5	3.15	0.29	2.8	2.8	0.3	0.19
BW, NI (2)	7.8	3.13	0.24	2.8	2.7	0.3	0.20
CHI, IR (1)	8.0	3.07	0.22	3.3	2,7	0.3	0.23
CHI, IR (2)	8.0	3.08	0.22	3.2	2.7	0.3	0.23
CHI, NI (1)	8.0	3.11	0.24	3.0	2.7	0.3	0.27
CHI, NI (2)	7.7	3.07	0.24	3.1	2.7	0.3	0.23
CON, IR (1)	7.9	3.10	0.25	3.1	3.2	0.3	0.25
CON, IR (2)	7.9	3.12	0.24	3.0	3.0	0.3	0.23
CON, NI (1)	8.0	3.06	0.21	3.1	2.6	0.3	0.22
CON, NI (2)	7.5	3.15	0.21	3.1	2.6	0.3	0.21

Treatment abbreviations: BW: Buckwheat; CHI: Chicory; CON; glyphosate sprayed control; IR: Irrigated; NI: not irrigated. Replicate number is within parenthesis.

A two-dimensional model which met calculated RSQ and stress values criteria was used to create MDS consensus plots which showed that panelists found significant differences in wine aroma among under-vine cover crop treatments for 2012 (Figure

3.4). For 2012 wines, both irrigation and under-vine cover treatments had significant effects on wines, and wines were found to be distinct from each other.

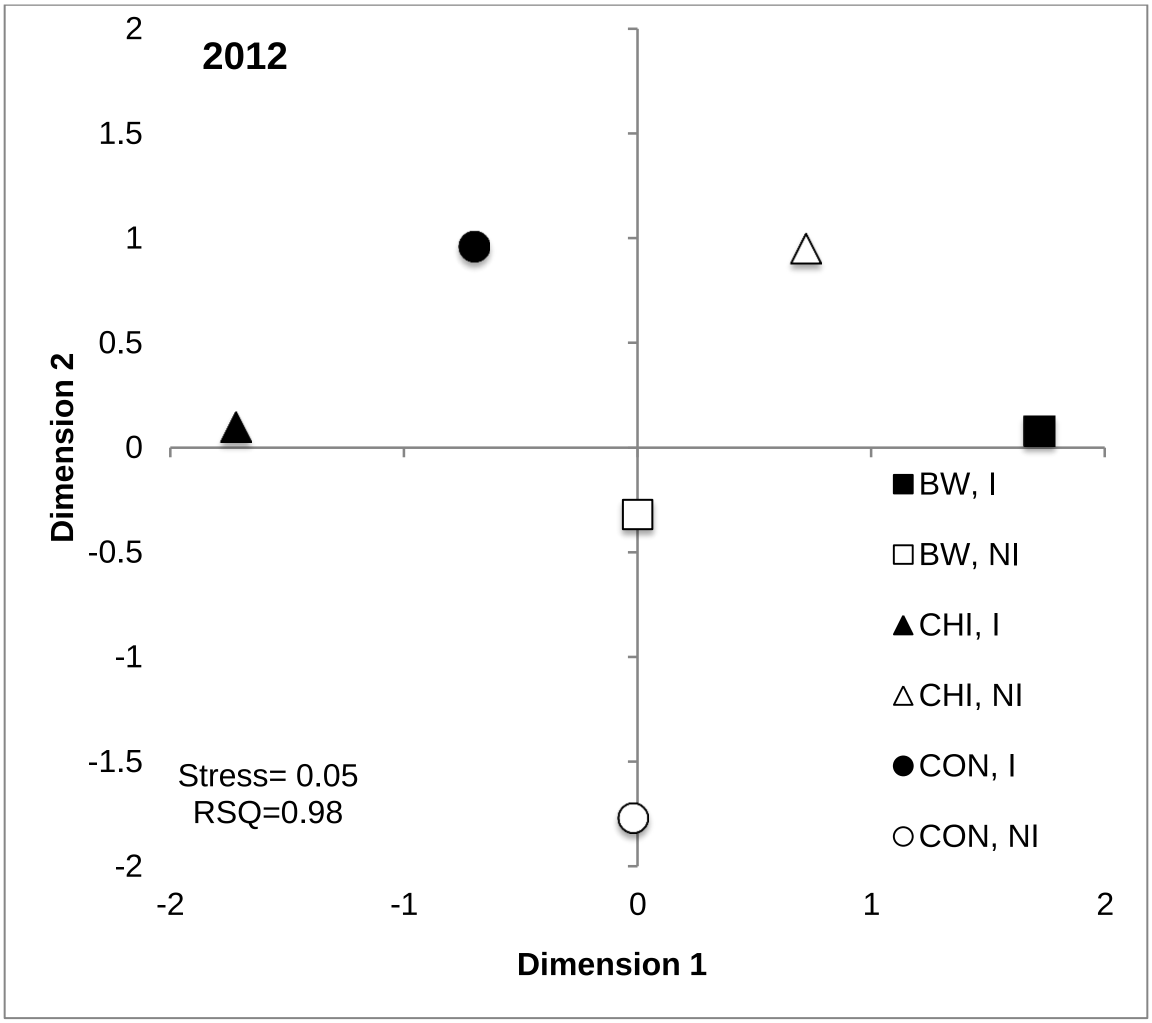

Figure 3.3 Two-dimensional consensus plot of aroma similarity ratings of Riesling wines from 2012. Treatment abbreviations: BW: Buckwheat; CHI: Chicory; CON: Glyphosate sprayed control; IR: Irrigated; NI: Not irrigated.

Discussion

In this experiment, annually established under-vine cover crops, with and without irrigation, were tested as an herbicide replacement to induce competition and restrict vine vigor. Both cover crops in this study offered the benefits of removing herbicide use on the vineyard floor, which would include the elimination of the documented risks of using glyphosate, including runoff (Edwards et al. 1980) and toxicity to vineyard soil organisms (Renaud et al. 2004; Schnurer et al. 2006). However, previous work has shown that reduced vine vegetative growth and yields can result when vegetation was maintained in vineyard floor interrows (Lopes et al. 2008; Sweet and Schreiner 2010; Wheeler et al. 2005) and under-vine rows (Hatch et al. 2011; Tesic et al. 2007; Krasnow et al. 2013). Previous studies have shown that cover crops have helped reduce excessive vigor and yield concerns in rain-fed vineyards, bringing pruning weights and yields closer to the legally regulated values in Italy (Sicher et al. 1993) and closer to the ideal Ravaz index values for vine balance in Portugal (Monteiro and Lopes 2007).

In cool and humid climates like the Northeast, vine growth can be excessively vigorous which can cause deleterious canopy shading and conditions for disease (Smart 1986; Vasudevan et al. 1998). To rectify the situation, canopy management practices estimated to cost $718/acre for an established, vertically trained *V. vinifera* vineyard in the Finger Lakes region (Yeh et al. 2013), must be employed to alleviate vigorous growth conditions. If under-vine cover crops cause a reduction in growth that improved canopy conditions, fruit and wine quality could be altered without as many expensive canopy management practices.

In the second year of establishment, chicory decreased shoot length and diameter, leaf layer number, and occlusion layer number in the canopy which was then reflected in greater cluster and leaf exposure flux availability values and a greater proportion of sunlight exposed clusters. So while eliminating herbicide use the vineyard, the use of chicory in under-vine rows may have additional disease management and labor reducing benefits by decreasing vegetative growth and shade producing layers and increasing the measured sunlight exposure within the canopy (Table 3.7).

Chicory was found to reduce individual berry weights and number of berries per cluster in the second year of the study (Table 3.5). Reduced berry size is associated with improved fruit quality and generally desired by winemakers (Roby et al. 2004; Singleton 1972). Decreasing the cluster compactness or tightness is also correlated with reduced incidence of rot (Vail and Marois 1991; Zabadal and Dittmer 1998), but cluster architecture and disease incidence were not quantified in this study. Increased measures of cluster sunlight exposure have been correlated with decreased incidence of disease and increased spray penetration in the canopy (Austin et al. 2011). Further investigation of how chicory or other species of cover crops in under-vine rows can enhance disease management by improving canopy and cluster characteristics may illuminate additional benefits of maintaining under-vine vegetation.

While reducing pruning weights and total yield per vine, chicory did not significantly alter the Ravaz index values in either year (Table 3.6) and values remained within the suggested range of 5 to 10 kg/kg for a divided canopy systems (Kliewer and Dokoozlian 2005). This suggests chicory did not impact vine balance while reducing unwanted excessive vegetative growth and improving cluster attributes. However, the benefits of reduced canopy and disease management costs must be weighed against the reduction in yield, which could be economically prohibitive for growers in the Finger Lakes region.

At harvest, chicory was found to have titratable acidity values 0.80 to 1.01 g/L, less than the herbicide control in both years. This is in accordance with previous work where using resident vegetation (Monteiro and Lopes 2007) and chicory (Wheeler et al. 2005) in vineyard interrows improved fruit quality over maintaining conventional bare soil by reducing titratable acidity. Increasing light in the canopy has been found to promote accelerated ripening with lower acid levels due to respiration of malic acid (Ruffner 1982; Lakso and Kliewer 1978; Smart 1985) and pre-veraison water deficits have been found to reduce malate levels (Matthews and Anderson 1988). For the cool and humid Northeast where deacidification can be necessary, using a chicory cover crop could offer growers a way to improve juice quality. Soluble solids and pH of juice were not impacted by under-vine cover crop treatments.

The reduced stem water potential of vines in the chicory and irrigated buckwheat treatments compared to the irrigated control on one date in the pre-veraison period in 2013 suggests that competition for water may be imposed by under-vine cover crops under some circumstances. Pre-veraison water deficits are known to restrict growth (Matthews et al. 1987), but vines in this study were still well hydrated as is typically seen in the Finger Lakes region, and not within a midday water potential range that would typically stunt vegetative growth (Intrigliolo et al. 2009).

There is a complex dynamic between the soil moisture and nutrient status that under-vine cover crops may affect. There was a significant interaction effect between cover crop and irrigation treatments on midday stem water potential on two measurement dates, indicating that different soil moisture conditions resulted in different vine responses to under-vine cover crops in midday stem water potential. It is likely that the physiological demands of the two different cover crops were very different at this point of the season; buckwheat with its rapid annual cycle (Bjorkman and Shail 2010) would have had much less of a demand for water and/or nutrients at this point, unlike chicory which was still actively flowering. This difference may have resulted in different soil moisture and nutrient demands by the cover crop and induced differing levels of competition with the grapevines. Soil moisture content will inhibit nitrogen mineralization and therefore uptake by grapevines (Freeman and Kliewer 1983). Cover crops may induce competition directly by consuming water and/or nutrient resources, but soil moisture conditions will also determine the availability and mineralization of nitrogen in the system. Using under-vine cover crops like chicory may monopolize on a combined effect of increased water and nutrient stress imposed by the under-vine chicory cover crop.

While buckwheat reduced nitrogen content of petioles collected at veraison in both years, it did not reduce measures of vegetative growth or yield measures like chicory, which was found to reduce nitrogen content only in the second year (Table 3.4). These results indicate that more than a reduction grapevine nitrogen concentration is required for under-vine cover crops to impose a sufficient level of competition to reduce growth for the given site conditions within two years of establishment. It is also possible that previously recommended petiolar nitrogen content levels at veraison (Wolf 2008) are excessively high for the Finger Lakes region. The studies in this and the previous chapter noted nitrogen levels below recommended levels (Table 2.4, Table 3.4), but visual nitrogen deficiency symptoms were never noted in any year and vigorous shoot growth rates were apparent (Table 2.5, Table 3.8). Further investigation of what is a limiting vine nitrogen content for vines in the Finger lakes region is warranted. Long term evaluation of annually established under-vine cover crops would also be beneficial, to better understand the impacts over several years, and varying climatic conditions, including severe winters and poor seasonal ripening conditions.

Reduced nitrogen content of vines is linked with lower nitrogenous compound concentrations like YAN in the fruit (Bell and Henschke 2005). While chicory did reduce both petiolar nitrogen content at veraison and YAN of juice in 2013, buckwheat reduced petiolar nitrogen in both years, but did not have a significantly lower YAN. This indicates there are other factors that contribute to the dynamics between the nutrient competition from under-vine cover crops, vine nutrient uptake, and the production of nitrogenous compounds in fruit that need to be better understood for the nutrient competition effects of under-vine cover crops.

Panelists detected differences in the aromas of wines from the different under-vine treatments (Figure 3.3) when wines were subjected to multi-dimensional sorting. Knowing that the use of under-vine cover crops reduced vegetative growth, canopy density, and yields, it is important to consider that light exposure in the canopy is known to affect aromatics in Riesling and this is possibly the source of the differentiation. Decreased canopy shading will increase concentrations of C13 norisoprenoids, including vitispriane, TDN, and β-damascenone in Riesling (Meyers et al. 2013) and chicory was found to generate significantly greater sun exposure on clusters and leaves at veraison in 2013, but not in 2012. Chicory was found to introduce sufficient competition to reduce shoot growth during July, and this is a critical pre-veraison period when sunlight exposure is known to increase TDN aroma precursor concentrations in

Riesling (Kwasniewski et al. 2010), but EPQA data was not taken until later when there were not significant differences in shoot lengths. Cover crops may have impacted the development of important aromatics if the light environment was altered before the time of EPQA measurement at veraison, and contributed to the detectable differences in wine aromatics during multi-dimensional sorting analysis. Further analysis of the fruit sunlight exposure before veraison would help clarify this potential source of wine aromatic variation.

The reduced petiolar nitrogen in vines in the chicory and buckwheat treatments may also have influenced wine aromas. In previous studies, nitrogen deficiency was found to decrease the production of critical aroma precursors in the grapes (Chone et al. 2006) and depressed nitrogen levels were associated with lower volatile thiol precursor concentrations (des Gachons et al. 2005). The reduced nitrogen concentrations induced by using buckwheat and chicory as under-vine cover crops may have resulted in decreased aromatic precursor production and therefore wine aroma development. In a previous study in New Zealand, wines produced from Cabernet Sauvignon vines with a chicory in-row cover crop were rated better than cultivated and herbicide treatments, with riper fruit aromas and flavors and received overall higher scores (Wheeler et al. 2005). This study also showed that chicory reduced vegetative growth and decreased petiole nitrate concentrations (Wheeler et al. 2005), and these factors may have contributed to the enhanced wine characteristics. Further sensory studies examining consumer preference for wines grown with annually established under-vine cover crops are needed to understand how cover crops influence wine quality.

While established on an annual basis in this experiment, chicory has a biennial growth habit that often lives as a short term perennial (Hall and Jung 2008). Chicory had greater biomass and total coverage than the buckwheat treatment by veraison in 2013, and a significantly greater biomass in 2013 than 2012, reflecting the biannual growth habit (Figure 3.2), whereas buckwheat is an annual with a short life cycle of 40 days (Bjorkman and Shail 2010) that went to seed by veraison in this study. While reported to not be able to withstand cultivation, chicory produces deep taproots (Hall and Jung 2008) which exploit a much greater depth of the soil profile than shallow rooted buckwheat. The rapid establishment, deep rooting habit, and persistent activity of chicory differentiates it from other annually established species of cover crops like buckwheat in this study, and those in the previous chapter, and likely accounts for its ability to induce conditions that resulted in reduced vegetative growth, yields, and altered juice and wine characteristics. Further research is needed to examine if chicory as a long-term established under-vine cover crop would continue to suppress vine nitrogen levels and growth and eventually induce too much competition, negatively stunting vine growth or reducing yields to an economically infeasible level.

Conclusion

This study hypothesized that using annually established under-vine crops would reduce vine growth by competing for limited resources. However the results of this study demonstrated that using buckwheat as an under-vine cover crop for two years did not alter measure of vine growth or yields, but chicory reduced measures of vegetative and reproductive growth and increased sunlight exposure in the canopy compared to a conventional glyphosate maintained strip. In established vineyards where vegetative growth can be excessive and must be actively managed for optimal wine grape quality, herbicide use may be unnecessary and maintaining more environmentally sustainable cover crops in under-vine rows should be considered. In a Riesling vineyard in the cool and humid Northeast where excessive vegetative vigor promoted deleterious canopy shading and requires canopy management, chicory used as an under-vine cover crop reduced unwanted excessive vegetative growth by reducing shoot length, cane diameters, pruning weights, leaf layers in the canopy, and increased canopy light exposure. Midday stem water potential and petiole nitrogen content at veraison were found to be affected by under-vine cover crop treatments and indicate that under-vine cover crops like chicory can compete with grapevines for resources like water and/or nutrients during the growing season. Chicory also affected juice quality by positively reducing titratable acidity, but negatively by reducing YAN content. Further work to better understand how cover crops can be used to improve resulting wine aroma and quality should be conducted to further encourage sustainable alternatives to herbicide use in Northeastern vineyards.

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Chapter 4. Conclusions and Future Work

These experiments showed that annual species of under-vine cover crops used as an herbicide replacement were not found to affect measures of vine growth, yield, or juice and wine characteristics, but chicory did reduce vegetative growth, yields, and altered titratable acidity. All under-vine vegetation treatments were found to significantly impact wine aroma. These studies are one step towards promoting environmentally sustainable alternatives to herbicide in vineyards that promote environmental and soil health. Understanding the potential long term effects of replacing herbicide use with vegetatin in under-vine rows on vine growth and yields is needed. Further evaluation of other species of cover crops is warranted to further explore what vegetation may be used in under-vine rows to reduce unwanted vegetative growth. Continued sensory tests are needed to better elucidate the relationship between perceived wine aroma and under-vine management, including preference testing to understand how consumers may react to the altered wine aromas. Additionally, understanding how eliminating herbicide use in the vineyard may impact the agro-ecosystem and micriobiota on the grapes and how this may affect fermentation would be valuable to Finger Lakes winemakers using natural fermentations.